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EXPERIMENTAL INVESTIGATION OF A  $4\frac{1}{2}$ -STAGE TURBINE WITH VERY HIGH STAGE LOADING FACTOR

II - Turbine Performance

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	The experimental test program results of a $4\frac{1}{2}$ -stage turbine with a very high stage loading factor are presented. A four-stage turbine was tested with and without outlet turning vanes. The $4\frac{1}{2}$ -stage turbine achieved a design point total-to-total efficiency of 0.853. The outlet turning vane design point performance was 0.4 percent of the overall $4\frac{1}{2}$ -stage turbine efficiency. Tests were conducted at various levels of Reynolds number and indicated decreases in turbine efficiency and equivalent weight flow with decreasing Reynolds number.				
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#### SUMMARY

The experimental results of the program are presented. The object of this program was to provide technology for fan drive turbines utilizing very high stage loading. A four-stage turbine was tested with and without outlet turning vanes.

The four and one-half stage turbine achieved a total-to-total efficiency of 0.853 at the design equivalent speed (N/ $\sqrt{\theta_{\rm CT}}$  = 2171.2 rev/min) and design total-to-total pressure ratio (P<sub>T1</sub>/P<sub>T3</sub> = 2.66).

The outlet turning vanes were successful in turning the turbine exit flow to axial at all of the operating conditions investigated. The test results indicate that approximately 0.5 percent loss in overall 4-1/2-stage turbine efficiency at 100% speed and design work is attributed to the outlet turning vane performance when based on measured turbine exhaust total pressures. However, a difference of only 0.08 percent loss in performance was indicated when based on calculated exhaust total pressure.

The 4-1/2-stage turbine radial efficiency profile showed high efficiency in the pitchline region with a slight decrease toward the tip and a heavy loss in the hub region.

Reynolds number testing, accomplished by varying the inlet pressure (density level), indicated decreases in efficiency and equivalent weight flow with decreasing Reynolds number. Radial efficiency profiles indicated the hub region sustained the greatest increase in loss with decreasing Reynolds number.

#### INTRODUCTION

A twenty-one month analytical and experimental investigation program was conducted to provide technology for fan drive turbines utilizing very high stage loading. The technology is specifically applicable to multi-stage configurations for advanced high bypass ratio, direct lift turbofan propulsion system applications.

The expanding role of the turbofan engine stems from its inherent design flexibility to exploit the cycle advantage afforded through a small gas generator core in conjunction with a fan selected to provide improved fuel consumption and thrust characteristics. Advanced research investigations of the propulsion requirements for direct lift fan engine systems indicate these systems will have high bypass ratio turbofan engines.

The size of a lift engine is as important as its weight. A V/STOL airplane will require twelve to fourteen of these engines to be mounted, involving considerable pod area and weight. If twelve or more lift engines are installed per airplane, it is apparent that engine cost will be a significant factor in the total airplane cost. Since number of parts and components has an effect on cost, there is an incentive to reduce the number of stages in a fan drive turbine.

The foregoing considerations of V/STOL engine requirements suggest the following fan drive turbine requirements:

- 1. Minimum number of stages (short, less cost)
- 2. Some SFC penalty acceptable (relative to cruise engine)

Combined with the low rotor speed (non-geared), these requirements imply a fan drive turbine with meanline average loading (gJ $\Delta$ h/2 $\Sigma$ U $_p$ <sup>2</sup>) in the 2-2.5 range and efficiencies in the 80% to 85% range for lift engine operation. A fan drive turbine design of this type can save two to three stages with minimum impact on lift engine fuel consumption, while having a beneficial effect on installation weight, drag, and cost.

The specific objective of this program was to design, build, and test a very highly loaded four-stage fan drive turbine with outlet turning vanes.

The program was divided into two phases encompassing eight task items of activity. The first phase covered Task Items I and II. The purpose of Task I was to investigate parametric turbine velocity diagram studies. Task II involved selecting one turbine design for which detailed aerodynamic, mechanical, and rig modification sub-tasks were performed. The results of Tasks I and II were reported in Reference 1.

The second phase covered the remaining tasks of this program including the following: (a) fabrication and procurement of turbine blading, casing

pieces, and running gear, (b) vibration bench testing and fatigue endurance testing of rotor blades, (c) modification of turbine rig, (d) instrumentation of turbine test section, (e) performance test of turbine, and (f) analysis of performance tests and writing of performance report. The purpose of this report is to present the results of the task items completed in Phase Two of this program.

#### AERODYNAMIC EVALUATION

#### TURBINE

Requirements - The analysis and design of the 4-1/2-stage fan drive turbine which was investigated are presented in Reference 1. The turbine design requirements are presented below:

é	Constant pitch diameter	19.00 in. (48.26 cm.)
•	Number of stages	4-1/2
•	Equivalent weight flow	25.07 1bm/sec (11.37 kg/sec.)
•	Inlet swirl angle	0.0 degrees
٠	Exit swirl angle with turning vanes	0.0 degrees
•	Velocity leaving outlet turning vanes related to inlet critical velocity	0.376
•	D-Factor of outlet turning vanes at mean radius	0.4
•	Average mean radius loading $(gJ\Delta h/2\Sigma U_p^2)$	2.5
•	Equivalent specific work	25.88 BTU/1bm (60242.32 joules/kg
•	$W\sqrt{T_{\mathrm{T}}}/P_{\mathrm{T}}$ at inlet	38.85 $1 \text{bm} - \sqrt{^{\circ} R} / (\text{sec-1bf/in}^2)$ (25.55 $\text{kg} - \sqrt{^{\circ} R} / (\text{sec-n/cm}^2)$ )
•	$N/\sqrt{T_T}$	95.33
•	Equivalent mean blade speed (constant for all stages)	180 ft/sec (54.86 m/sec)

Configurations Tested - A 4-1/2-stage turbine with constant pitchline diameter was tested in an air turbine facility to obtain detailed design and off design aerodynamic performance data of the Very Highly Loaded Turbine reported in Reference 1. The design percent total energy produced by each stage ( $\Delta h_{stage}/\Delta h_{turbine}$ ) was 28.5% on stage one, 26.5% on stage two, 26.0% on stage three, and 19% on stage four. The corresponding aerodynamic pitchline loadings (gJ $\Delta h/2\Sigma U_p^2$ ) for each stage were 2.85, 2.65, 2.60, and 1.9 for stages one, two, three, and four respectively. The turbine design velocity diagram is presented in Figure 1 and the flowpath is shown in Figure 2.

The turbine was also tested as a four stage configuration in order to assess the design and off design performance of the Outlet Turning Vanes.

Photographs of the turbine blading used in the test program are presented in Figures 3 through 16.

#### TEST APPARATUS AND INSTRUMENTATION

Test Facility - The two turbine configurations were tested in the General Electric Company's Evendale Air Turbine Test Facility, which is a dual purpose facility capable of evaluating either single stage high pressure turbine or multistage fan drive turbine performance. Figure 17 shows a typical test facility configuration.

Turbine air is supplied from the Central Air Supply System of the Component Test Complex, which consists of an arrangement of five multistage centrifugal compressors driven by synchronous motors through speed increasing gears. Staging these compressors in series or parallel or using them as exhaustors provides the various modes of operation normally required for the turbine operation. The compressor discharge air is then directed through various auxiliary systems in order to provide air that is filtered to ten micron particle size, dried to minus 70° F dewpoint, and indirectly heated to the desired temperature by passing it through a heat exchanger. Flow enters the test section through a specially shaped scroll which smoothes out flow disturbances and provides a uniform stream to the turbine inlet. Air enters the first stage nozzle through a convergent bellmouth section and a constant annular passage approximately three inches long. Turbine discharge air leaves through a constant annular passage approximately nine inches long and expands into the exhaust plenum.

The generated turbine horsepower is extracted by means of a low speed waterbrake, specifically designed for this test series, which was directly coupled to the turbine shaft by flexible couplings and a short spool piece. This waterbrake design provides excellent speed stability throughout the entire turbine operating map.

A two-level trip system is used to guard against overspeed and excessive temperature or vibrations. The level 1 trip is signaled by an overspeed or bearing over-temperature. Level 2 is signaled by excessive vibrations or critical support system temperatures or pressures.

The turbine facility control console is located in the Test Cell Control Room, illustrated in Figure 18. All the necessary controls and critical turbine or facility monitoring instrumentation are strategically located to enable one man control of the entire test facility. This feature is a direct result of the utilization of analog closed-loop control circuits for setting and maintaining all prime turbine variables. Turbine parameters of inlet temperature, inlet pressure, speed, discharge pressure, and rotor thrust bearing load can all be maintained automatically at pre-set values.

Data Acquisition System - The data acquisition system consists of a digital recorder linked to a paper tape and paper punch tape printer. A total of 61 temperatures and 236 pressures, as well as other specific turbine performance parameters, were recorded by the digital recording system.

Temperature measurements were obtained with precision manufactured Chromel-Alumel thermocouple wire. Sensors in any one plane of measurements use wire from one spool. Calibration samples of wire were cut from each sensor lead and both samples and sensor leads were oven cured for 28 hours at approximately 400° F. The wire samples were then calibrated over the expected temperature range against a Platinum Resistance Thermocouple which is traceable to the National Bureau of Standards, resulting in correction curves which were applied to the temperature measurements in the data reduction program.

Calibration curves were also established to determine temperature recovery at various expected Mach number ranges and flow incidence angles using a specially designed calibration stand with a 2.5 inch free jet nozzle capable of a Mach number range from 0.2 to 1.0. Corrections were made in the data reduction program using the calibration curves.

The thermocouple leads terminate in a Copper Alloy Thermal Sink (CATS), which is thermally insulated to minimize temperature gradients. To arrive at the absolute value of any temperature sensor, the absolute temperature of the CATS block was measured, using both a water-ice bath reference and an electron-ically controlled Ice Point Reference System. The latter was used to determine absolute temperature levels, but both systems were continually compared. The electrical output of each thermocouple was measured at this CATS block and the signal was amplified and directed to the digital recorder.

Turbine rig pressure measurements were obtained by the use of precision strain gage pressure transducers which convert pneumatic signals to electrical outputs. The pressures enter the control room pneumatically and terminate in electrically controlled scanners which systematically direct each pressure signal to a transducer. The transducer electrical outputs were amplified and directed to the digital recorder. All transducers of this type have a common excitation and output amplification. Each data reading contains the excitation voltage sensed at the transducer, the transducer zero, and a known calibration signal which was recorded through all its associated electrical circuitry. The repeatability of these parameters was continually monitored to preclude any measurement errors.

Pressure calibrations were performed prior to each test run using a precision dead weight tester for above-atmospheric calibrations, and a quartz manometer for sub-atmospheric calibrations. Both units were frequently calibrated and their precisions are directly traceable to the National Bureau of Standards. All pressure transducers used have characteristic curves compiled in a computer library file, to which each pre-run calibration was compared for discrepancies.

The digital recording system is linked to the General Electric 635 Computer by means of a GE Terminet 300 located in the Control Room. This feature enabled reduced data to be printed out in the Control Room within five minutes of the reading of a test point.

<u>Instrumentation</u> - Figure 19 shows the location of the instrumentation used in the testing of the two turbine configurations.

Temperature and pressure instrumentation was mounted on the leading edge of the inlet strut frame, station 0, Figure 19, on each of ten struts which were spaced 36 degrees apart, and located approximately 12 inches upstream of the first stage stator. Temperature was measured with 25 Chromel-Alumel thermocouples mounted in high recovery stagnation tubes affixed to five of the struts 72 degrees apart. The thermocouples were grouped five to a strut and were located radially at the area center of five equal annular areas. Total pressure was measured by 25 Kiel-type probes located on five alternate struts, also 72 degrees apart, and located in an identical manner as the thermocouples. These pressures were measured independently by means of the scanner-transducer system and then arithmetically averaged in the data reduction program. They were also pneumatically averaged, using a specially designed averaging block, measuring an average output on a single pressure transducer. The temperatures at this station were used for turbine inlet temperature.

Inlet static pressure was measured with five equally spaced static pressure taps located on both the inner and outer casings in a straight annular section about 2-1/2 chord lengths upstream of the first stage stator, Station 1.0, Figure 19. These static pressure taps were used to check the circumferential uniformity of the flow and to calculate the turbine inlet total pressure. Five Kiel-type total pressure probes were also installed in the inlet plane and spaced 72 degrees apart to serve as a check of the circumferential uniformity of the flow.

Interstage static pressures were measured with four static pressure taps installed 90 degrees apart at the leading and trailing edge planes of the stator blade rows on both the inner and outer bands, Station 1.2 through 1.8. The circumferential location of the pressure taps was selected to coincide with the position of the mean streamline. A similar arrangement of static pressure taps was used at the leading edge plane of the outlet turning vanes, Station 1.9 and 1.95.

Four turbine outlet static pressures were measured on both the inner and outer casings at Station 2 and approximately one inch downstream of the outlet turning vanes. These static pressure taps were spaced 90 degrees apart. Turbine outlet total temperature, total pressure, and flow angle were also measured at Station 2 over an angle subtending about 11 degrees by a radially and circumferentially traversing combination probe. A fast response pressure differential servo-system aligned the probe with the flow and provided an electrical output proportional to the flow angle. Total temperature, total pressure, and flow angle were recorded on X-Y chart recorders as functions of either radial immersion or circumferential position. The instrumentation at Station 2 was used to calculate outlet total pressure as described in Appendix A.

At Station 3, approximately four inches downstream of the outlet turning vanes, turbine outlet total temperature and total pressure were measured with six fixed circumferential arc rakes 60 degrees apart, located radially at the centers of six equal annular areas. A total of 36 total temperatures and 72 total pressures were measured. Each rake contained twelve Kiel-type pressure elements located side-by-side and six shielded thermocouple probes side-by-side. The total pressures were averaged both arithmetically and pneumatically in the same manner as the inlet pressure measurements. Six static pressure taps were also installed on the inner and outer walls at this station and were located 60 degrees apart.

Four turbine outlet static pressures were measured on both the inner and outer casings immediately aft of the outlet turning vanes and approximately one inch downstream of the outlet turning vanes. These static pressure taps were spaced 90 degrees apart. Six static pressure taps were also installed on the inner and outer walls about four inches downstream of the turning vanes and were located 60 degrees apart.

Air flow to the turbine was measured using a calibrated circular arc venturi which was operated at critical flow conditions. The venturi inlet pressure and temperature were measured using wall static pressure taps and Chromel-Alumel air thermocouple probes, respectively, located upstream of the venturi throat.

Three independent speed measurements were provided by an indicating system consisting of a 60-tooth gear attached to the turbine shafting and three stationary magnetic sensors located very close to the gear teeth. Electrical impulses resulting from the passing of each tooth provided an electrical frequency proportional to turbine speed. Electrically time integrating this signal provided the speed indication, accurate within  $\pm$  1 rpm. During the course of each data reading, twelve different samples of speed were recorded and arithmetically averaged.

Two independent techniques were employed for the measurement of shaft torque. The primary system consisted of a dual bridged shaft-mounted torque sensor. The strain sensitive spool section was located between the turbine shaft and the waterbrake shaft with a specially designed slip ring mounted behind the waterbrake to transmit electrical signals to the digital recorder. Each bridge was excited with its own independent electronics system and read out or displayed through the digital data acquisition system. The secondary torque measurement was obtained by means of a load cell located beneath a lever arm attached to the cradled waterbrake stator housing. The load cell also employed independent signal conditioning and readout electronics.

Torque calibrations were performed in place using a precision torque arm and dead weights, whose weight values are traceable to the National Bureau of Standards. Dead weight calibrations were conducted prior to each test run to verify repeatability of torque zeros and bridge linearity. In addition, extensive temperature calibrations were made to define torque zero and modulus changes over the operational temperature range, even though these effects are less than 0.25 percent.

#### TEST PROCEDURE

The turbine inlet conditions were set at 720° R and 45 psia, with the exception of the test points noted in the table below. These test points could not be set at the above conditions due to test facility and waterbrake limitations.

$\frac{{}^{\mathrm{P}}_{\mathrm{T}_{1}}/{}^{\mathrm{P}}_{\mathrm{S}_{3}}}{}$	Percent Design Speed	P <sub>T1</sub> , psia	T <sub>To</sub> , R
2.28	60	45	700
1.97	80	38	705
1.97	90	38	710
1.97	100,110,120	38	717
1.78	60,80,90,100,110,120	38	693

The performance mapping of the turbine was accomplished by selecting test points within the following range of variables:

- Speed 60, 80, 90, 100, 110, 120 percent design speeds
- Total-to-total pressure ratio from a maximum corresponding to 125% design work at design speed to a minimum equal to the pressure ratio that produces 60% design work at design speed.

Additional testing was done in the vicinity of the design point at 720° R and inlet pressures of 25, 38, and 50 psia to investigate effects of Reynolds number.

The following performance data were obtained at each test point:

- Turbine weight flow
- Rotative speed
- Torque
- Inlet total temperature
- Inlet total and static pressures
- Outlet absolute flow angles
- Outlet total and static pressures

- Outlet total temperatures
- Flowpath hub and tip interstage static pressures.

At each test point three complete sets of data were recorded and processed through the on-line computer which permitted an immediate evaluation of the reduced data.

Key performance parameters were continually monitored to insure accuracy and consistency of the test data. The design point was periodically reset throughout the testing to monitor the repeatability of the facility and the design point calculations.

One radial and three circumferential traverses were made at each test point to record the turbine exit total pressure, total temperature, and absolute flow angle. The circumferential traverses were taken at 10, 50, and 90 percent of the outlet turning vane height.

A detailed turbine exit survey was taken at the design speed and design pressure ratio. The survey included three radial traverses at 0, 50, and 100 percent of the circumferential traverse sector which was an arc of 11.32 degrees, and seven circumferential traverses at 10, 20, 30, 50, 70, 80, and 90 percent of the outlet turning vane height.

#### DATA REDUCTION PROCEDURE

Turbine Overall Performance - Two calculation schemes were used to reduce the overall performance data. The two methods differed in only one respect. The preliminary test cell data reduction program used measured exit total pressures for all performance calculations whereas the final data reduction was performed using calculated inlet and exit total pressures. This exit total pressure was calculated from continuity using outlet total temperature, outlet static pressure, measured weight flow, and outlet flow angle. The outlet total temperature was derived from the inlet total temperature, specific enthalpy drop obtained from the torque, speed and weight flow measurements. The outlet static pressure was calculated as the average of the measured exit hub and tip static pressures. The outlet flow angle was taken as an integrated average flow angle from the traverses. A more detailed description of all of the calculation procedures used in the data reduction may be found in Appendix A.

The following overall performance parameters were determined for each of the three readings taken at each test point:

- 1. Calculated inlet total to outlet total pressure ratio as obtained from indirect measurement.
- 2. Calculated inlet total to outlet static pressure ratio as obtained from indirect measurement.
- 3. Equivalent speed.
- 4. Equivalent weight flow.

- 5. Equivalent weight flow-speed parameter (product of equivalent speed and equivalent weight flow).
- 6. Equivalent torque.
- 7. Equivalent specific work.
- 8. Ideal equivalent specific work.
- 9. Efficiency based on calculated total-to-total pressure ratio.
- 10. Blade-jet speed ratio based on total-to-static pressure ratio.

These parameters are tabulated in Table I.

Outlet Turning Vane Exit Survey Calculations - The total pressure, total temperature, and absolute flow angle, which were recorded during the turbine exit surveys at the design point, were used in the construction of contour plots showing local efficiency. The local efficiencies were calculated from the following parameters:

- Measured inlet total temperature
- Calculated inlet total pressure based on continuity using measured inlet static pressure and measured airflow
- Local exit total temperature measured by the traverse probe
- Local exit total pressure measured by the traverse probe

Reynolds Number Calculations - The turbine Reynolds number was varied by operating the turbine over a range of inlet pressures (densities) while maintaining the design pressure ratio. A Reynolds number for each bladerow was calculated on the basis of leaving gas velocity, throat dimension and suction surface length of the particular blade as shown in the following expression which is derived in detail in Appendix B.

$$R_{N_{\underline{1}}} = \left(\frac{12 \text{ W L}}{\mu \text{ n d}_{0} \text{ h}}\right)_{\underline{1}}$$

where:

W = measured airflow (1bm/sec)

 $\ell$  = suction surface length (inches)

 $\mu = bladerow exit viscosity (1bm/sec-ft)$ 

n = number of airfoils

h = height of blade at throat (inches)

d = blade throat dimension (inches)
i = ith stage

The turbine overall Reynolds number was obtained by energy weighting the individual bladerow Reynolds numbers as follows:

$$\bar{R}_{N} = \sum_{i=1}^{m} \Delta h_{i} R_{N_{i}} / \sum_{i=1}^{m} \Delta h_{i}$$

#### EXPERIMENTAL RESULTS AND DISCUSSION

<u>Turbine Overall Performance</u> - The reduced data and calculated parameters are presented in the following curves:

- a. Equivalent torque versus calculated total-to-total pressure ratio.
- Equivalent weight flow versus calculated total-to-total pressure ratio.
- c. Equivalent specific work versus calculated total-to-total pressure ratio.
- d. Total-to-total efficiency versus blade-jet speed ratio.
- e. Total-to-total efficiency versus calculated total-to-total pressure ratio.
- f. Equivalent specific work versus equivalent weight flow speed parameter with lines of constant calculated total-to-total pressure ratio, constant speed, and constant efficiency superimposed.

The above curves utilize constant values of percent equivalent design speed as a parameter and are presented in Figures 20 through 25.

Figures 26 through 29 show comparisons of the reduced data for equivalent torque, equivalent weight flow, equivalent specific work, and efficiency, respectively, to the pre-test predictions originally presented in Reference 1. The data show agreement with predicted trends but not with the predicted absolute levels. The disagreement in magnitude was primarily due to the selection of loss coefficients (such as bladerow efficiencies and rotor and stator total pressure recovery factors) which are considered as constants in the vector diagram performance calculations.

The lower predicted design point equivalent weight flow is considered to be a mismatch between the stage one stator physical throat area and the design intent.

Normalized interstage hub and tip static pressures versus axial station are presented in Figure 30 for the design speed at each turbine pressure ratio tested. These plots indicate that as turbine total-to-total pressure ratio increases the first stage hub reaction decreases from positive to negative. This downward trend was predicted but the absolute value of the

measured reactions was lower than the level predicted by the Turbine Computer Program.

Turbine Exit Survey - Figures 31 and 32 present the efficiency contours of the 4-1/2- and the 4-stage turbine configurations as a function of percent radial height and circumferential position. The local efficiencies were determined from the radial and circumferential total pressure and total temperature traverse surveys in the turbine exit plane. The 4-1/2-stage efficiency contour plot covers an arc of 2.1 outlet turning vane pitches and the 4-stage efficiency contour plot covers an arc of 1.56 fourth stage stator pitches. These plots illustrate the large radial efficiency gradients in the hub and tip regions of the flowpath. The 4-1/2-stage contours show the pronounced outlet turning vane wakes especially in the vicinity of the tip. The low efficiency regions at the hub are considered to be the strong secondary flow fields generated by the high turning stator and blade airfoils.

The reader is cautioned against drawing conclusions about the relative performance of the two configurations from these plots since their degree of accuracy is only sufficient to make qualitative but not quantitative judgment.

Figure 33 compares the turbine radial total pressure ratio distributions for the two configurations. Caution should be used when interpreting this plot since the two turbines were operating with slightly different equivalent energy extractions. This accounts for the exit total pressure for the 4-1/2-stage build being slightly greater than that for the 4-stage turbine.

A comparison of the radial exit swirl angle profiles for the two configurations are shown in Figure 34. The plot graphically shows the reduction in swirl achieved by the outlet turning vanes which turned the flow from positive 30 degrees at the inlet pitchline to minus one degree at the exit pitchline. These curves were drawn by averaging the radial swirl traverses made at three circumferential positions for the major design point of each configuration.

The design point radial total-to-total efficiency profile shown in Figure 35 for the 4-1/2-stage turbine was constructed by mass weighting the circumferential traverses of total pressure and total temperature at seven radial positions.

The high efficiency at the pitchline is a measure of the full potential of the turbine. The gradual fall-off in efficiency toward the tip and the steep decrease toward the hub are indications of the effects of strong secondary flow fields generated by the high turning bladerows. Additional improvements in the hub and tip regions are needed to enable the bladerows to fully utilize their potential.

Reynolds Number Effects - The turbine Reynolds number was varied for the 4-1/2-stage turbine by operating over a range of inlet pressures (thus changing the density level) while maintaining a constant turbine pressure ratio.

In Figure 36, a plot of total-to-total efficiency versus blade-jet speed ratio at constant total-to-static pressure ratio and with lines of constant inlet pressure is presented. The plot illustrates the effects of varying inlet pressure on turbine efficiency as the turbine operates through its speed range. The increase in efficiency becomes smaller with each increase in turbine inlet pressure (and corresponding increase in turbine Reynolds number) until at some point, no further efficiency increase will result. The curves show that the inlet pressure at which no efficiency increase occurs was attained in this test.

Radial efficiency profiles based on fixed rake data for two inlet pressures are presented in Figure 37. The profiles were constructed for inlet total pressures of 45 psi and 25 psi, corresponding to high and low Reynolds numbers, respectively. Figure 38 illustrates the change in efficiency between the low and high Reynolds number points. This figure indicates that the greatest change in efficiency due to Reynolds number effects occurs in the hub region.

Plots of total-to-total efficiency and equivalent weight flow versus turbine Reynolds number appear in Figures 39 and 40. Each point on the plots represents data obtained at or near the design operating point. Both turbine efficiency and equivalent weight flow increase with increase in Reynolds number up to a point where Reynolds number is approximately one million. Above this value, efficiency and equivalent weight flow level off at a constant value.

Outlet Turning Vane Performance - Figure 41 depicts the total pitchline turning done by the outlet turning vanes at the design and off-design operating points. This curve illustrates that the outlet turning vanes were highly successful in being able to turn the turbine exit flow to axial at all of the operating conditions investigated.

Figures 42 and 43 show the results of two independent methods used to determine the percent turbine performance loss attributed to the outlet turning vanes. It is assumed that this loss is reflected by the difference in efficiency between the 4- and 4-1/2-stage configurations at a given equivalent specific work extraction. Figure 42 was based on calculated exit total pressure and it indicates approximately 0.08 percent additional loss in overall efficiency at the turbine design point. Figure 43, however, was based on measured exit total-pressure and it shows the 4-1/2-stage design point efficiency to be approximately 0.5 percent below the 4-stage turbine. This level of loss appears to be more realistic when compared with compressor outlet guide vane performance.

Recommended Improvements - The analysis of the data acquired during the air turbine testing of the 4- and 4-1/2-stage configurations indicate specific areas of performance deficiencies in the 4-1/2-stage very highly loaded fan turbine. Several recommendations to improve the overall design and off design performance based on these test results are outlined below:

• Utilize leaned stators as reported in Reference 2. This will decrease the rotor hub inlet relative Mach numbers below their current levels which are approximately 0.7. Leaned stators will

also decrease the leakage loss across the rotor tip shrouds by decreasing the axial static pressure drop across the blade tip section.

- Use tandem stator airfoils in stages 2, 3 and 4. Reference 3 indicates the performance of a highly loaded two-stage turbine was increased 1.2 percent by installing a tandem stator in stage two. Tandem airfoils also increase the performance in the turbine hub region.
- Redesign the outlet turning vane and remove the design criteria that the diffusion factor equal 0.4. Parametric studies preceding the design of the outlet turning vane indicated higher performance could be achieved with diffusion factors higher than 0.4.

The design point measured radial efficiency profile indicates a significant loss in performance in the hub region of the turbine. It is suspected that this is the manifestation of the strong secondary flow fields generated by the high turning blade rows. In view of the experimental results it is highly desirable to test additional configurations to isolate the performance of the individual stages and to determine the nature of the low performance in the hub region.

#### MECHANICAL EVALUATION

The rotor blades were vibration tested under laboratory conditions to establish their fundamental and higher frequency modes. Fatigue tests were conducted to establish the endurance capability of the blades while operating in an air turbine environment. These tests substantiated the analytical effort reported in Reference 1.

#### LABORATORY TEST OF ROTOR BLADE AIRFOILS

<u>Vibration Testing</u> - A series of vibration tests were conducted to substantiate the predicted natural frequencies reported in Reference 1. The fundamental and higher frequency modes of vibration were determined for fixed fixed (restrained at the hub and tip) end conditions.

The top tangs on the shrouds were machined off and a steel block was brazed to the top of the shrouds to allow for a tight clamping surface. The clamping was done across the pressure and suction sides of the blade's shroud region to simulate the "locking up" of the blade's shroud during air turbine operation. Due to the tight clamping necessary to get a good frequency response, the actual end condition imposed on the blades was a fixed end condition. The dovetail—shank region was clamped in the same manner. In the actual turbine, the blades will lock up in the tangential direction and should be free to move in the axial direction. To get a rigid clamp of the blade in the tangential direction at the shroud, and then allow an axial displacement to occur, is not feasible in a laboratory setup. This is due to the mass of the clamping setup and the lack of knowledge to the degree of displacement necessary to simulate actual turbine operation. The predicted blade analysis was done for each blade under fixed—fixed end conditions for comparison to the experimental results and is presented in Table III.

Campbell Diagrams incorporating the most probable modes of vibration are presented in Figures 44 through 47. The close agreement between the theoretical results and experimental data for the fixed-fixed end conditions provides the necessary credibility to the predicted axial modes.

Based on the theoretical analysis and the experimental results it was concluded that the blades would not experience any excessive vibrations during air turbine operation.

Fatigue Endurance Testing - Fatigue endurance testing was performed on test specimens from each blade row. The top portions of the blades were cut off which increased the first flex frequency response and shortened the fatigue testing time. The blades were clamped at the dovetail and fatigued in first flex to get an indication of the blade material endurance strength at an "A" ratio  $(\sigma a/\sigma m)$  of infinity. These stresses are shown on the Goodman diagram in Figure 48. The stress levels experienced by the test specimens were measured by strain gages located in the most likely regions of failure. First flex was used since it is usually the easiest to instrument. Runout for a particular

stress level was set at a million cycles before it was increased in increments of 10 KSIDA. Considering testing time and the cyclic endurance strength of the 410 stainless steel, a million cycles to failure would adequately indicate the level of the endurance strength. The stage one blade failed at 80 KSIDA in the trailing edge at 2.5% span. This is approximately 20 KSIDA less than average properties. The reason was due to a sharp trailing edge which caused a stress concentration in that region. Stages two and four failed in the trailing edge region at the stress level depicted on Figure 48. three failed on the leading edge above the root fillet. Photographs of the blade failures are shown in Figure 49. The blades would have experienced failure at different points if they had been restrained at the tip, due to a different strain distribution. It isn't the failure location that is important in this particular test, but the level of stress at failure. The last three stages exhibited an endurance level above the curve on the Goodman Diagram. This curve is based on 10<sup>7</sup> cycles to failure and since a million cycles were used as a limit before increasing the stress, the test values would be above the curve.

Table IV illustrates the number of cycles run at the failure stress. Stage one, two and three were started at 50 KSIDA with 10 KSIDA incremental increases after  $10^6$  cycles until failure. Stage four was started at 70 KSIDA with incremental increases until failure.

The laboratory fatigue data compared favorably with the average fatigue characteristics for the 410 stainless steel. The material in a machined blade configuration suffered little or no fatigue strength deterioration relative to the polished barstock specimens established as the norm. It was concluded that the rotor blades had no inherently weak points and had sufficient fatigue endurance capability for successful air turbine operation.

#### SUMMARY OF RESULTS

A four and one-half stage turbine was tested in order to evaluate the performance of a very highly loaded fan turbine with outlet turning vanes. The most significant results of the testing and analysis are summarized below:

- 1. The four and one-half stage turbine achieved a total-to-total turbine efficiency of 0.853 at the design speed and pressure ratio  $(N/\sqrt{\theta}_{cr} = 2171.2, P_{T_1}/P_{T_3} = 2.66)$ .
- 2. The four stage configuration was tested to isolate the performance of the outlet turning vanes. The test results based on measured turbine exhaust total pressures indicated a 0.5 percent loss in four and one-half stage turbine efficiency can be attributed to the outlet turning vane performance. However, a difference of only 0.08 percent loss in performance was indicated when based on calculated exhaust total pressure.
- 3. The outlet turning vanes were successful in turning the turbine exit flow to axial at all of the operating conditions investigated.
- 4. High efficiencies in the pitchline region were indicated by the radial efficiency profiles. Efficiency drops were noticed toward the hub and tip with the effect more pronounced in the hub region.
- 5. Reynolds number testing showed that total-to-total efficiency and equivalent weight flow decrease with decreasing Reynolds number. Radial efficiency profiles indicated the greatest increase in loss with reduced Reynolds number occurs in the hub region.

#### APPENDIX A

#### OVERALL PERFORMANCE CALCULATION

Exit Flow Angle - In order to evaluate turbine performance on the basis of turbine exit total pressure calculated from continuity, an average turbine exit flow angle,  $\overline{\Gamma}$ , was determined. This angle is the absolute value of the deviation from axial direction, irrespective of sign. The turbine exit flowpath was divided into streamtubes, and measured values of swirl angles, total pressure, and total temperature were used to satisfy continuity within each streamtube. The turbine exit measured static pressure was assumed to vary linearly from hub to tip. The determination of the average turbine exit flow angle proceeded as follows:

$$(\rho \ V \ A_{ann} \cos \Gamma)_{avg} = \sum_{i=1}^{m} \rho_i \ V_i \ A_i \cos \Gamma_i$$

there:

$$\rho_{\mathbf{1}} \quad V_{\mathbf{1}} = P_{S_{\mathbf{1}}} \quad \sqrt{\frac{\gamma_{\mathbf{S}}}{RT_{\mathbf{1}}}} \sqrt{\frac{2}{\gamma - 1}} \quad \left[ \left( \frac{P_{\mathbf{T}}}{P_{\mathbf{S}}} \right)_{\mathbf{1}}^{\left( \frac{\gamma - 1}{\gamma} \right)} - 1 \right] \sqrt{\left( \frac{P_{\mathbf{T}}}{P_{\mathbf{S}}} \right)_{\mathbf{1}}^{\frac{\gamma - 1}{\gamma}}}$$

 $P_{_{\rm T}}$  = Measured total pressure at center of i-th streamtube.

P<sub>S</sub> = Static pressure at center of i-th streamtube based on linear variation in measured static pressure from hub to tip

 $T_{T}$  = Measured total temperature at center of i-th streamtube

 $\Gamma$  = Swirl angle

 $\rho$  = Density

V = Absolute velocity

A = Area

m = Number of streamtubes

i = Subscript denoting streamtube value

ann = Subscript denoting value for total annulus

avg = Subscript denoting average value for total annulus

The average velocity representing the turbine exit flow field was calculated by conserving the axial and tangential components of momentum, such that

$$v_{avg} = \left(v_{u_{avg}}^2 + v_{z_{avg}}^2\right)^{1/2}$$

where

$$v_{u_{avg}} = \begin{pmatrix} m \\ \Sigma \\ i=1 \end{pmatrix} v_{i} | \sin \Gamma_{i} |$$

$$\sum_{i=1}^{m} w_{i}$$

$$V_{z_{avg}} = \begin{pmatrix} m \\ \Sigma & W_i & V_i & \cos \Gamma_i \end{pmatrix} / \begin{pmatrix} m \\ \Sigma & W_i \\ i=1 \end{pmatrix}$$

and

$$v_{i} = \sqrt{2g \operatorname{Jc}_{p} T_{i}} \left[ 1 - \left( \frac{P_{S}}{P_{T}} \right)_{i}^{\frac{\gamma - 1}{\gamma}} \right]$$

V = Tangential component of absolute velocity

V = Axial component of absolute velocity

W = Weight flow through i-th streamtube

The average turbine exit total temperature was determined through an energy balance of the annular streamtubes.

$$T_{\text{avg}} = \begin{pmatrix} m & & \\ \Sigma & W_{i} & T_{i} \end{pmatrix} / \begin{pmatrix} m & & \\ \Sigma & W_{i} & & \\ i=1 & & \end{pmatrix}$$

The average density at the turbine exit was obtained from the equation of state.

$$\rho_{avg} = \frac{{}^{P}S_{avg}}{R T_{S_{avg}}}$$

where

$$T_{S_{avg}} = T_{T_{avg}} - \frac{v_{avg}^2}{2g Jc_p}$$

Calculated Outlet Total Pressure - After obtaining the average turbine exit flow angle, the exit total pressure was calculated in the following manner:

$$P_{T_3} = P_{S_3} \left(1 + \frac{\gamma - 1}{2} M_3^2\right)^{\gamma/\gamma - 1}$$

Turbine exit Mach number, M3, was determined from the following relationship:

$$\frac{\sqrt{\sqrt{R} T_{T_3}}}{\frac{P_S A_{ann} \cos \Gamma_{avg}}{\sqrt{1 + \frac{\gamma - 1}{2} M_3^2}} = \sqrt{\gamma g} M_3 \sqrt{1 + \frac{\gamma - 1}{2} M_3^2}$$

Turbine exit total temperature,  $T_{T_2}$ , was determined as follows:

$$T_{T_3} = T_{T_0} - \frac{\Delta h}{c_p}$$

where

$$\Delta h = \frac{2\pi N\tau}{60 JW}$$

N = Turbine rotative speed

τ = Measured torque

 $T_{T_{O}}$  = Measured turbine inlet total temperature

W = Measured turbine weight flow

<u>Inlet Total Pressure</u> - Turbine inlet total pressure was calculated in the same manner as the turbine exit total pressure. The calculation used measured airflow, measured inlet total temperature, the average of measured hub and tip static pressures, and the assumption of zero inlet swirl angle.

<u>Performance Parameters</u> - The remaining parameters used in the overall performance calculation were obtained as follows:

$$δ = P_{T_1}/14.696$$
 $θ_{cr} = T_{T_0}/518.688$ 
 $ε = 1.0 (for γ = 1.4)$ 

Equivalent Speed, N EQV =  $N/\sqrt{\theta_{cr}}$ 

Equivalent Weight Flow, WA EQV =  $W\sqrt{\theta_{cr}} \epsilon/\delta$ 

Weight Flow-Speed Parameter, WAN EQV = WNε/60δ

Equivalent Torque, TQ EQV =  $\tau \epsilon / \delta$ 

Equivalent Specific Work, DH EQV = 
$$\frac{\Delta h}{\theta_{cr}} = \frac{2\pi \ N\tau}{60 \ J \ \theta_{cr}}$$

Ideal Equivalent Specific Work, DHI EQV =

$$\left(\frac{\Delta h}{\theta_{cr}}\right)_{ideal} = c_p T_0 \left[1 - \left(\frac{P_{T_3}}{P_{T_1}}\right)^{\frac{\gamma-1}{\gamma}}\right] / \theta_{cr}$$

Total-to-total Efficiency, ETA TT =

$$\eta_{\text{TT}} = \left(\frac{\Delta h}{\theta_{\text{cr}}}\right) \left(\frac{\Delta h}{\theta_{\text{cr}}}\right)_{\text{ideal}}$$

Blade-Jet Speed Ratio, U/CO =

$$v = \left\{ \frac{v_{m}^{2}}{c_{p} T_{0} \left[1 - \left(\frac{P_{S_{3}}}{P_{T_{1}}}\right)^{\frac{\gamma-1}{\gamma}}\right]} \right\}^{1/2}$$

#### APPENDIX B

#### REYNOLDS NUMBER CALCULATION

The turbine Reynolds numbers were based on the energy weighted Reynolds numbers of each blade row as defined below:

$$\overline{R}_{N} = \begin{pmatrix} m \\ \Sigma & \Delta h_{1} & R_{N_{1}} \end{pmatrix} / \begin{pmatrix} m \\ \Sigma & \Delta h_{1} \\ i=1 \end{pmatrix}$$

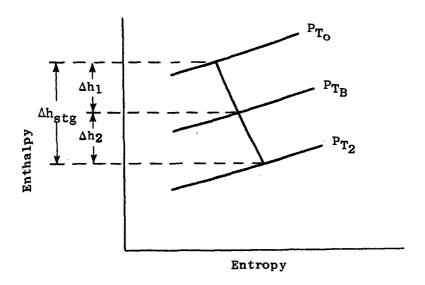
where

$$R_{N_{1}} = \left(\frac{12 \text{ W L}}{\mu \text{ nd}_{0} \text{ h}}\right)_{1}$$

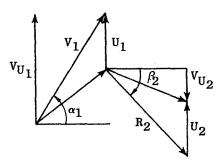
and  $\Delta h_i$  = Equivalent fractional energy extraction of i-th bladerow.

The viscosities  $\mu$  were obtained from Reference 5.

The equivalent fractional energy extraction of each bladerow is derived as follows. The velocity diagram energy for each stage can be divided into two constituents associated with the stator and rotor leaving energies. This division of the total stage energy is illustrated on the following enthalpy-entropy diagram:



The energies  $\Delta h_1$  and  $\Delta h_2$  can be expressed in terms of the stage velocity diagram parameters as shown below:



From the sketches,

With the appropriate combination of terms and algebraic manipulations the above expressions can be simply expressed as:

$$\Delta h_{stg} = \Delta h_1 + \Delta h_2 + \frac{{U_1}^2 - {U_2}^2}{2gJ}$$

where

$$\Delta h_1 = \frac{v_1^2}{2gJ} \left[ \left( \frac{v_1}{v_1} \right) \left( 2 \sin \alpha_1 - \frac{v_1}{v_1} \right) \right]$$

and

$$\Delta h_2 = \frac{R_2^2}{2gJ} \left[ \left( \frac{U_2}{R_2} \right) \left( 2 \sin \beta_2 - \frac{U_2}{R_2} \right) \right]$$

The terms  $\frac{{v_1}^2}{2gJ}$  and  $\frac{{R_2}^2}{2gJ}$  are the energy equivalents of velocity leaving

the stator and rotor respectively. The terms 
$$\left[ \left( \frac{U_1}{V_1} \right) \left( 2 \sin \alpha_1 - \frac{U_1}{V_1} \right) \right]$$
 and  $\left[ \left( \frac{U_2}{R_2} \right) \left( 2 \sin \beta_2 - \frac{U_2}{R_2} \right) \right]$ 

are properties of the velocity diagrams at the stator and rotor exit planes.

The velocity diagram parameters used in this analysis for each blade row were calculated using the Turbine Computer Program described in Reference 6.

### APPENDIX C

### LIST OF SYMBOLS

A	Area (in. <sup>2</sup> , cm <sup>2</sup> )
c <sub>p</sub>	Specific heat at constatnt pressure (ft <sup>2</sup> /sec <sup>2</sup> °R, m <sup>2</sup> /sec <sup>2</sup> °K)
D	Diameter (in., cm)
do	Throat dimension (in., cm)
Δh	Turbine energy extraction (Btu/1bm, joules/kg)
$^{\Delta h}$ stg	Stage energy extraction (Btu/1bm, joules/kg)
h	Height at bladerow throat (in., cm)
.2	Blade or vane suction surface length (in., cm)
М	Mach number
m	Number of bladerows, streamtubes, or stages
N	Rotational speed (rev/min)
n	Number of vanes or blades
Ps	Static pressure (psia, newtons/cm <sup>2</sup> )
PS3	Turbine exit static pressure (psia, newtons/cm <sup>2</sup> )
P <sub>T</sub>	Total pressure (psia, newtons/cm <sup>2</sup> )
$P_{T_1}$	Turbine inlet total pressure, station 1 (psia, newtons/cm <sup>2</sup> )
$P_{T_3}$	Turbine exit total pressure, station 2 (psia, newtons/cm <sup>2</sup> )
R	Gas constant (ft <sup>2</sup> /sec <sup>2</sup> °R, m <sup>2</sup> /sec <sup>2</sup> °K)
R <sub>2</sub>	Rotor exit relative gas velocity (ft/sec, m/sec)
R <sub>N</sub>	Reynolds number
$\overline{R_N}$	Energy weighted overall Reynolds number
T <sub>S</sub>	Static temperature (°R, °K)
T <sub>T</sub>	Total temperature (°R, °K)
$T_{T_O}$	Turbine inlet total temperature, station 0 and station 1 (°R, °K)

```
T_{T_3}
               Turbine exit total temperature, station 2 (°R, °K)
                Spacing (in., cm)
t
               Wheel speed (ft/sec, m/sec)
U
V
               Absolute velocity (ft/sec, m/sec)
                Mass flow rate (1bm/sec, kg/sec)
W
\Delta h/\theta_{cr}
                Equivalent specific work (Btu/1bm, joules/kg)
W\sqrt{\theta_{\rm cr}} \ \epsilon/\delta
                Equivalent weight flow (1bm/sec, kg/sec)
N/\sqrt{\frac{\theta}{\theta}}
                Equvalent rotative speed (rev/min)
                Weight flow - speed parameter (1bm/sec<sup>2</sup>, kg/sec<sup>2</sup>)
WNε/60δ
gJ∆h/2U<sup>2</sup>
                Loading factor
                Vane inlet absolute flow angle (degrees)
\alpha_{0}
                Vane exit absolute flow angle (degrees)
\alpha_1
^{\beta}1
                Blade inlet relative flow angle (degrees)
β2
                Blade exit relative flow angle (degrees)
Γ
                Stage leaving swirl angle (degrees)
F
                Turbine out flow angle (defined in Appendix A)
                Specific heat ratio
γ
 δ
                Ratio of turbine pressure to pressure at standard sea level
                conditions
                Function of \gamma defined as \frac{\gamma_{\rm SL}}{\gamma} \left\{ \left[ \frac{\gamma+1}{2} \right]^{\gamma/(\gamma-1)} \left[ \frac{\gamma_{\rm SL}+1}{2} \right]^{\gamma_{\rm SL}/(\gamma_{\rm SL}-1)} \right\}
 ε
                Total-to-total efficiency
 n_{TT}
^{\theta}cr
                Squared ratio of critical velocity at turbine inlet temperature
                to critical velocity at standard sea level temperature
                Viscosity (1bm/sec-ft, kg/sec-m)
 μ
                Blade-jet speed ratio
                Density (in., cm)
 ρ
```

```
Alternating stress (ksi, newtons/cm²)

Mean stress (ksi, newtons/cm²)

Torque (ft-lbf, m-newtons)

teq

Equivalent torque, τeq = τε/δ (ft-lbf, m-newtons)
```

### Subscripts

Z

a	Alternating
В	Relative to rotor blade
h	Hub
i	Current axial station, stage, or streamtube, or ideal
m	Mean
p	Pitch
R	Relative
r	Radial component
t	Tip
u	Tangential component

Axial component

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Reduced Test Data and Calculated Performance Parameters, 4-1/2-Stage Configuration. Table I.

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P10/P53	2.958	2.966	2.970	2.965	5.064	5.965	2.962	2.966	2.954	2-952	2.956	2.950	166.	200	966	586	.951	.952	. 954	.651	- 052	.650	.655	.652	.655	5.00		2000	630	.650	.649	.648	• 652	.651	160.	644.	. 950	. 955	4000	682.	0.7	172.	• 278	.272	2.270	2.277	2.270
PT0/PT3	69	9	9	99.	• 66	-67	• 67	.67	.68	19.	. 68	S S	Š.	ċ	- / -	7.0	7.	.71	.71	.47	.47	.47	•47	.46	.47	4.	9 4	0 7	. 4 . 4	4	.43	• 43	• 42	• 42	42	69.	٠٠. د د د	• 69			-	• 14	4.	4.	4		•14
P 10	45.06		3	-	9.0	5.2	3.1	7	5.0	5	•	ا بو	, .	- - -	- 4 - 4 - 4 - 4		5	1.5	5.1	5.1	5.1	501	٠. ب		: ان د کا	= <		2 9		-	5.1	5.0	٠. د	٠ ا		0 .		0	•	ָרָ מַיּ	٠ د د	٠.	- I	0 .			-
PC# NDES	1.00 0.00 0.00 0.00	<b>3</b> 3	•	63	6.3	9 P	9	2	<b>0</b> ;	<b>3</b>	<b>&gt;</b> <	•	<b>=</b> :	s',	ج ج		i.N	N	$\sim$	N	24	N	-1	н .	- :	0 0 c	> =	٠,٠	9 0	8	69	9.0	01	<b>.</b> 0	ပ	<b>3</b> :	ə :	ə ,	T o	- <b>1</b>		<b>⇒</b> :	a :	<b>⇒</b> ∶	<b>⇒</b> :	<b>⊃</b> :	א
RDG	9.8	<b>~</b> •	•		0	9	0	•	0	_	<b>•</b> •		~ .	<b>-</b> 4 ₹	- ۲	1 -	•	-	-	-	€	N	~	∾ :	N (	125	u o	u c	V M	מיו	3	~	m	2	2 1	2	2	<b>*</b> 3 ·	• •	• •	• •	•	•	•	• •	•	4

Reduced Test Data and Calculated Performance Parameters, 4-1/2-Stage Configuration (Continued). Table I.

FLOWANG	α	æ,	κ. •	. σ.	α,	٠,	٧.	×.	×.	۲,	٠ı		` `	^	۲.		ç.	٠,	٠, ٥	•	٥,		٠. ا	M. I	į,		٠.		٠,	. "	. M	٥.	۰.	٠. ١	٠,٠	٠.	٠.		6	α (	× •		α.	
07/0	/cF•	, c1 •	, כן פּ	2/1	1/2	.188	106	108	٠. کې د	, 	0.0	907	156	-1/2	2/1.	2/		V 0	0.00	200	.247	901.		,	6	201.	.115	5 T T	) = -	7 7	100	.178	1/0	) Y	2 4	100	.207	700	20/	972	072	977.	0.1095	
ETA II	.865	. 865	2 4	866	.866	849	.849	.849	• 838 :	. x 38	0000°	857	.856	.860	.860	.860	. 842 242	842	240		.607	.852	45.52	. 855 258	. 652 K	0.8518	.780	8	16/0		849	.857	.857		1 4 4 L	841	- 804	808	·804	159	19/	C	0.8507	
AOT, IHO	4.50	4.49	4.5 7.0	, 00	4.00	4.70	4.71	4.71	6.55				0.65	0.73	0.72	0.70	2. 3.	6.7			0.08	1.71	0.72	0.74	00.00	٠ <u>٠</u>	7.73	1:1		+ U	7.86	7.87	7.88	/ B /		90.0	8.12	6.13	g.15	.15	40.	5	30./01	
DH FOV	1.16	1.15	4.0	7.7		86.0	86.0	0.9A	7.23	7.23	22.	7 - 7 8	7 6.68	7.84	7.83	7.82	7.51	7.51	7 - 52		6.86	6 - 18	6.18	6.19		6.1	3.84	3-85	46.0	7 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1	5.17	5.39	5.33	5.34		- 6	4 . F.R.	4.58	4 · 5 A	3.79	3.74	3.67	26-116	•
TO EUV	1.2	6.9		9 0	9.	373.6	372.4	375.0	1.1	800.3	0.000	3.0	595.5	410.3	410.8	410.2	208-6	208.7	20%	010.7	018.3	288-2	289.0	289.4	7.707	45	963.9	963.4	962-6	470.0	4.5	292.4	292.9	294-1		100.1	916.8	6.5	9.9	0 • 2	5.9	758.9	2276-84	
WAN EUV	81.4	81.2		1		716	95.0	91.5	50.4	50.0	* · · ·	24.6	83.00	38.1	38.0	37.5	94.	84.5	20.40.0 20.00 20.00	7.00	20	18.4	8.3	T . A .	7	917.59	58.4	9.95	ည်း သို့	9 0	5.00 5.00 5.00	49.1	49.2		0		35.2	35.2	35 • 0	59.0	59.5	9.99	918.24	
WA EUV	.48	• 41	4.0		7.0	9.0	98	06.	.65	69.	65	000	9	.12	٠. در	.13	• 19	.26	2.	7.5	21	45	. 45	45	4.	4 4	2	.28	28	2	525	.58	58	59	\$ 0 V	6.4	59	.58	.58	19.	99.	9	25.436	
N E C V	107.	165.	9	30 E	499	598.9	6.00.8	597.1	753.0	753.7	753.1	, u	968.1	174.3	173.5	172.9	390.5	390.5	390.0	0.010	610.0	164.8	164.2	164.3	166.6	0.00	325 . 0	325.6	325.0	768.4	768.	990.2	9.066	991.0	210.2	210.5	434.0	434.1	433.5	655.6	652.8	652.6	2167.47	
P10/P53	2.274	2.273	2.272	2.277	0.075	2,275	2.270	2.277	1.964	1.963	1.964	1.964	C 96° F	1.965	1.964	1.965	1.964	1.963	1.965	1.950	1.964	2.968	2.961	2.964	2.954	2.455	1.780	1.779	1.779	1.770	1.778	1.773	1.774	1.773	1.780	1.781	1.788	1.780	1.780	1.776	1.772	1.774	2.958	
P10/PT3		٠.	÷.	~ ~			-	· 🕝	æ	æ	æ	ဆ္၀	Ξ.	. sc	æ	σ.	æ	æ	æ :	•	•	٠	÷	÷	9	çç	•	ŗ		•					•					.7		٠,	2.695	
PT0	5 . 8	9.0				. 0	9	5 . 1	7.9	7.99	E .	7.0	6 6	6.	7.9	7.9	7.9	7.9	7.9	. r	. 6	. 0	4.9	4.9	<u> </u>	4 10 5 - 0	6.7	7.9	7.9	2.0	, ,	5.	7.9	6.6	<b>5</b> 6	=0	6	7.9	7.9	7.9	7.6	7.6	37.94	
OU NDES	⇒	$\Rightarrow$	Ter.		4 -	48	I N	.N	T x	n 1	8.1	-f •	1.1	100	=	=	-	-	4	N .3	ے ن	1 =		>	2	2 C		0.1	0.1	<del>,</del>	7 -	2.6	42	S	э:	<b>=</b> =		-	-	N	N.	N	7 C C	,
Rus	4	S	30 1	n u	ם ע		ľ	E.	3	3	ø.	v v	9 K	9	•	•့င	Ŷ	ø	0	<b>^</b> '	~ ~	. ~	~	~	~	~ ~	. ~	8	æ	œ	<b>10</b> 00	9	20	8	∞ :	æο	٠.	. 0	0	6	0	0	197	

Reduced Test Data and Calculated Performance Parameters, 4-1/2-Stage Configuration (Continued). Table I.

18.76 2277.35 26.119 30.700 0.850 22.74.35 26.119 30.700 0.850 22.74.95 26.119 30.700 0.850 22.74.95 26.119 30.700 0.850 22.74.96 26.119 30.700 0.850 22.74.96 26.119 30.700 0.850 22.74.96 26.119 30.700 0.850 22.74.75 2741.75 2741.75 2741.75 2741.75 2741.75 2741.75 2741.75 2741.75 2741.75 2741.75 2741.70 27.850 0.850 20.10 22.84.44 26.11	918.76 2277.35 26.119 30.700 0.8518 0.10 921.35 2279.01 26.199 30.700 0.8518 0.10 921.35 2279.01 26.199 30.700 0.8528 0.10 921.35 2278.01 26.199 30.700 0.8528 0.10 921.35 2278.01 26.199 30.400 0.8528 0.10 921.35 2741.51 24.379 30.402 0.10 922.39 0.10 921.35 2741.51 24.379 30.402 0.10 922.39 0.10 922.39 2284.23 24.379 30.402 0.10 922.39 0.10	I. Reduced Test Data a	Pioto Data by	Z 2	ָל ל י	_	, ,	10 1 U	ու ա		במשמ לי	rgara		มี โ
918.76 2277.35 26.119 30.700 0.850 920.00 2274.35 26.119 30.701 0.855 921.35 2278.90 26.119 30.701 0.855 921.35 2278.90 26.118 30.701 0.855 921.35 2274.51 24.370 30.461 0.855 921.27 2741.51 24.370 30.461 0.798 921.27 2741.51 24.370 30.461 0.798 921.20 2284.23 26.186 30.461 0.798 921.00 2284.23 26.186 30.485 0.855 921.00 2284.23 26.186 30.485 0.855 921.00 2284.23 26.186 30.485 0.865 921.7 26.756 30.852 0.865 921.7 26.756 30.852 0.865 921.7 26.756 30.852 0.865 921.7 26.756 30.852 0.865 921.7 26.756 30.852 0.865 921.7 26.756 30.852 0.865 921.7 26.756 30.852 0.865 921.17 26.756 30.852 0.865 921.17 26.757 30.484 0.797 921.2 26.485 30.821 0.865 921.2 26.2 26.2 26.2 26.2 26.2 26.2 26.2	918.76 2277.35 26419 30.700 0.8508 0.18920.40 22289.90 20.189 20.040 22289.90 20.189 30.098 0.48530 0.18920.40 22289.90 20.189 20.049 20.27.35 22.289.90 20.18930 0.48530 0.18930 0.18	0/PT3 PT0/PS3 N E: V M	0/PT3 PT0/PS3 N E: V M	10/PS3 N Euv M	* 	Ì	A FOV	MAN EGV	10 E0V	DH FOV	DHI FOV	ETA II	0 1/0	FLOWANG
928.450 92278.90 9221.35 9228.46 9221.35 9228.49 921.35 9228.49 921.47 921.47 921.47 921.47 921.47 921.47 9221.50 9221.41 9221.50 9221.41 9221.41 9221.42 9221.41 9222.42 9221.41 9222.42 9221.42 9222.43 9222	928.408 2279.11 20.195 30.706 0.8550 0.1952.35 2278.90 20.187 30.098 0.8550 0.1952.35 2278.95 20.187 30.098 0.8555 0.1952.35 2278.95 20.187 20.195 20	00 37.92 2.694 2.958 2167.52	2.694 2.958 2167.52	.958 2167.52	167.52	N	5.4	18.7	277.3	6.11	0.70	.850	7	α
7.2.1.2.2	761.07 2741.51 20.0187 30.703 0.16727 30.703 0.16727 30.703 0.17928 4 170.02 24.370 30.470 0.7984 0.1701.05 2284.44 26.104 30.470 0.7984 0.1701.04 2284.44 26.104 30.470 0.7984 0.1701.04 2284.44 26.104 30.470 0.7984 0.1701.04 2284.44 26.104 30.470 0.185.5 0.195.0 30.490 0.2885.51 26.193 30.480 0.185.5 0.195.0 30.490 0.2885.51 26.193 30.480 0.185.7 0.195.0 30.480 0.195.0 30.490 0.2885.51 26.193 30.480 0.170.0	959 2172.15	2.695 2.959 2172.15	.959 2172.15	172.15	N :	5.4	20 m	279.0	61.9	07.0	.858. 		2.04
761.67 76	761.07         7741.51         24.370         30.430         0.7992         0.7992           761.07         2741.70         24.370         30.4451         0.7992         0.750           761.04         2284.23         26.194         30.4461         0.7994         0.19           920.14         2284.23         26.194         30.461         0.8536         0.1853           920.20         2284.23         26.194         30.486         0.1853         0.1853           991.20         2181.11         26.743         30.486         0.1853         0.1853           991.47         2727.21         24.30         30.486         0.1867         0.1967           761.15         2731.55         24.30         30.486         0.1867         0.1967           761.16         2727.21         24.30         30.486         0.797         0.1967           761.16         2727.32         24.30         30.486         0.797         0.1967           991.47         206.73         30.486         0.797         0.1967         0.1967         0.1967           991.48         26.60         30.486         0.1863         0.1863         0.1863         0.1863           991.48	00 42*0/ 2*594 2*950 51/2*39 5	2.694 2.950 c1/c+39 c	.950 £1/2.59 £	172.23	<i>1</i> 2	. 4	2.5	281.1	6.18	0.00	853		• •
761.05 2741.70 24.35 30.461 0.798 760.06 2741.64 24.33 30.470 0.798 760.01 2285.51 26.194 30.470 0.853 920.01 2284.23 26.195 30.4070 0.853 920.00 2284.23 26.195 30.463 0.865 991.09 2284.23 26.195 30.463 0.865 991.09 2282.72 26.195 30.486 0.865 991.45 2727.21 24.370 30.486 0.797 761.25 2727.21 24.370 30.486 0.797 761.25 2727.21 24.370 30.486 0.797 761.25 2727.22 24.370 30.486 0.797 761.25 2727.22 24.370 30.486 0.797 761.25 2727.23 26.4370 30.486 0.797 761.25 2727.23 26.4370 30.486 0.797 761.25 26.487 30.487 0.797 761.25 26.487 30.486 0.797 762.40 2253.67 26.487 30.487 0.797 762.40 2253.67 26.487 30.488 0.792 762.40 2253.67 26.487 30.488 0.792 762.40 2253.67 26.487 30.488 0.792 762.40 2253.67 26.487 30.498 0.887 762.40 2253.67 26.487 30.498 0.792 762.40 2253.67 26.487 30.498 0.792 762.40 2253.67 27.147 30.498 0.792 762.40 2253.67 27.148 22.498 0.792 762.40 2253.67 27.148 22.498 0.798 77.14 2253.67 27.148 22.498 0.792 762.40 2253.67 27.148 22.498 0.792 762.40 2253.67 27.148 22.498 0.792 77.148 22.290.70 27.148 22.290.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 22.200.70 27.148 27.14	761.05         2741.70         24.37         30.461         0.7984         0.7984           761.06         2284.23         20.193         30.487         0.853         0.853           920.00         2284.23         20.193         30.487         0.853         0.853           920.00         2081.11         26.775         30.863         0.8672         0.185           991.05         2081.11         26.775         30.863         0.8672         0.1867           991.6         2727.27         26.775         30.863         0.8672         0.1867           991.6         2727.32         26.430         30.484         0.797         0.1867           761.15         2727.32         26.430         30.484         0.797         0.1863           761.16         2727.32         26.430         30.484         0.797         0.1863           991.46         2727.32         26.487         30.484         0.797         0.1863           991.46         27.70         30.486         0.8653         0.1863           991.40         27.447         30.486         0.4873         0.1873           910.49         27.51.51         20.477         30.486         0.1873 <td>80 49.94 2.667 2.953 1734.96</td> <td>2.667 2.959 1734.90</td> <td>.953 1734.96</td> <td>734.96</td> <td>, .4</td> <td>6.3</td> <td>61.0</td> <td>741.5</td> <td>4 . 3.4</td> <td>0.43</td> <td>66/.</td> <td>7</td> <td>· ·c</td>	80 49.94 2.667 2.953 1734.96	2.667 2.959 1734.90	.953 1734.96	734.96	, .4	6.3	61.0	741.5	4 . 3.4	0.43	66/.	7	· ·c
760.66 2741.64 24.333 30.470 0.790 920.114 22284.44 26.191 30.686 0.853 920.50 2284.25 30.1853 30.686 0.853 920.50 2284.25 26.186 30.693 0.8653 991.75 26.187 30.693 0.867 991.08 2081.11 26.753 30.693 0.867 991.08 2081.11 26.753 30.693 0.867 991.75 20.2272.23 24.30 30.460 0.797 761.55 20.2272.32 24.30 30.460 0.797 761.55 20.2272.32 24.30 30.460 0.797 761.55 20.2272.32 24.30 30.460 0.797 761.55 20.2272.32 24.30 30.460 0.797 761.55 20.2272.32 24.30 30.460 0.797 761.55 20.2272.32 24.30 30.460 0.797 761.55 20.2272.32 24.30 30.460 0.797 761.55 20.2272.32 24.30 30.460 0.797 761.55 20.2272.42 26.677 30.723 0.8679 9.90.45 20.6577 26.677 30.460 0.797 762.20 2253.67 26.677 30.723 0.847 762.20 2253.67 26.077 30.723 0.847 762.20 2253.77 26.077 30.723 0.867 9.707 762.20 2253.77 25.078 32.467 0.797 762.20 2253.77 25.078 32.467 0.797 762.20 2253.77 25.078 32.467 0.797 762.20 2253.77 25.078 32.467 0.797 762.20 2253.77 25.078 32.467 0.797 762.20 2253.77 25.078 32.467 0.797 762.20 2253.77 25.078 32.467 0.797 762.20 2253.77 25.078 32.467 0.797 762.20 2253.77 225.078 32.467 0.797 762.20 2250.20 225	760-86 2741.64 24.333 30.4470 0.7966 0.1920.14 2284.44 26.191 30.466 0.185.59 0.1920.20 2285.21 26.194 30.466 0.185.59 0.1920.20 2284.23 26.186 30.4693 0.185.22 0.185.22 0.185.23 0.18	U 49.97 2.670 2.957 1734.9U	2.670 2.957 1734.90	.957 1734.90	734.90		6.3	61.0	741.7	4 - 32	U.46	.798	-	٧,
920114 2284.44 26.191 30.0686 0.853 920.50 2285.51 26.194 30.702 0.853 920.50 2285.51 26.194 30.702 0.853 990.50 2081.40 26.754 30.702 0.853 990.60 2081.41 26.754 30.633 0.863 990.60 2081.45 26.754 30.633 0.863 990.45 2727.21 24.30 30.460 0.797 761.55 24.30 30.460 0.797 761.55 24.30 30.460 0.797 761.55 24.30 30.460 0.797 761.55 24.30 30.460 0.797 761.55 24.30 30.460 0.797 761.55 24.30 30.460 0.797 761.50 20.65 24.30 30.460 0.797 761.50 20.65 24.30 30.460 0.797 761.50 20.65 24.30 30.460 0.797 761.50 20.65 24.30 30.460 0.797 760.42 20.66 24 26.60 30.821 0.865 971 26.60 30.821 0.867 971 26.60 20.	920.14 2288444 26.191 30.686 U-8535 0.1920.20 920.30 9289.00 2288444 26.193 30.686 U-8535 0.1920.20 920.30 920.30 920.30 920.30 920.30 920.30 920.30 920.30 920.30 920.30 920.30 920.30 920.30 920.40	84 50.06 2.671 2.958 1735.1	2.671 2.958 1735.1	.956 1735.1	735.1		6 . 3	9.09	741.6	4 . 3.3	0.47	96/.	-	٠,
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927.u8 2463.96 28.n8k 35.181 0.848 927.u9 2463.96 28.n8k 35.125 0.848 927.u9 2250.48 28.n8k 35.125 0.848 999.c1 2250.48 28.673 35.178 0.868 999.c5 2250.54 28.683 35.20 0.868 999.c5 2250.54 29.n97 35.273 0.871 0.70.c5 2043.78 29.n97 35.373 0.871 0.70.c5 2043.78 29.n97 35.373 0.871 0.70.c5 2043.78 29.n97 35.274 0.871 0.197.c5 2290.70 26.274 30.627 0.852 919.c6 2290.10 26.274 30.767 0.852 919.c6 220.274 30.767 0.852 919.c6 220.274 30.767 0.852 919.c6 220.274 30.767 0.852 919.c6 20.274 30.767 0.852 919.c6 20.274 30.767 0.852 919.c6 20.274 30.767 0.862 919.c6 20.274 30.767 0.862 919.c6 20.274 30.767 0.862 919.c6 20.274 30.844 919.c6 20.274 30.844 919.c6 20.274 30.844 919.c6 20.274 30.844	927.u8 2463.96 28.n8k 33.101 0.84485 0.19927.19 2463.96 28.n8k 33.125 0.84/8 0.19927.19 2251.41 2251.41 28.n8k 33.125 0.84/8 0.1999.20 2251.41 28.673 33.126 0.8641 0.1999.25 2251.54 28.683 33.20 0.8641 0.1070.46 20.43.51 29.n97 33.273 0.8719 0.11070.45 20.43.78 29.n97 33.374 0.8719 0.11070.45 20.43.78 29.n87 33.374 0.8719 0.11070.45 2290.70 26.9713 30.627 0.8954 0.199.48 2290.10 26.971 30.767 0.8954 0.199.48 2290.10 26.971 30.767 0.8954 0.199.48 26.18.34 29.669 35.193 0.8440 0.1929.34 26.18.34 29.669 35.193 0.8440 0.1929.45 26.17.59 29.659 35.140 0.8440 0.1901	UU 45.04 2.950 3.310 2170.6	2.950 3.310 2170.6	.310 2170.6	170.6		5.5	27.0	462.3	8.117	٥=٠	. 648	A - 1.040	٤.
927.19 2463.96 28.08 55.125 0.847 999.61 2251.41 28.675 35.126 0.864 999.61 2250.41 28.675 35.126 0.864 999.62 2250.54 28.6673 35.20 0.865 0.70.6 20.43.51 29.097 35.373 0.871 0.70.48 29.087 35.373 0.871 0.70.48 29.087 35.373 0.871 0.70.48 2290.70 29.087 30.627 0.852 919.58 2290.70 26.271 30.627 0.852 919.65 2290.70 26.271 30.767 0.852 919.65 2290.70 26.271 30.767 0.852 919.65 2290.70 30.741 0.852 919.65 26.204 32.741 0.852 929.58 2618.54 29.667 35.195 0.8454 929.58 2619.40 29.667 35.195 0.8454	927.19 2463.96 28.08 53.125 U.84/K U.1 999.41 2251.41 28.673 33.186 U.8641 U.1 999.29 3 33.20 U.8642 U.1 1070.46 2043.51 29.07 33.373 U.8719 U.1 1070.48 2043.78 29.087 33.374 U.8719 U.1 1070.48 2290.70 26.713 34.682 U.8719 U.1 919.48 2290.70 26.713 34.682 U.8718 U.1 919.48 2290.70 26.714 30.767 U.8524 U.1 919.48 2290.65 26.714 30.767 U.8524 U.1 919.48 26118.34 29.669 35.143 U.8524 U.1 929.48 2616.45 29.669 35.193 U.8440 U.1 929.49 2617.59 29.669 35.123 U.8440 U.1	u 44,99 2.95n 3.31u 2170.6	2.95n 3.310 2170.6	.310 2170.6	170.6		5.6	27.0	463.9	8.18	5.1.B	24. 3. 3. 3. 3. 3. 3. 3. 3. 3. 3. 3. 3. 3.	900	٠.
999.20	999-61 2251-41 28.675 55.186 U-8641 U-999-62 2250-48 26.673 55.186 U-8642 U-8647 U-8657 U-8647 U-8657 U-8647 U-8657 U-8647 U-8657 U-8647 U-8657 U-8647 U-8666 U-866	00 45.00 2.953 3.314 2170.6	2.953 3.314 2170.6	.314 2170.6	170.6		5	27.1	465.7	χ. α.	3.13	40.	500T-0	•
999.65 999.65 9250.54 999.65 2250.54 29.67 30.20 0.871 0.70.58 29.67 30.58 919.54 2290.10 26.21 30.67 0.871 0.872 0.873 0.873 0.873 0.873 0.873 0.873 0.874	999.55 7.250.40 20.673 35.200 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.210 0.4653 0.4710 0.48710 0.410 0.220 0.70 20.27 30.27 0.8574 0.10 20.29 0.20 20.20 20.20 20.20 20.20 20.20 20.20 20.20 20.20 0.20 20.20 0.20 20.	10 45.08 2.960 3.305 2382.7	2.968 3.305 2382.7	.305 2382.7	382.7		د د	) () ()	251.4	79.0	5.0	400	0.147	٠, ١
999.00 2250.09 20.663 30.200 0.000 0	999-55 2291-54 20-663 35-200 0-6033 0-60 10 10 10 10 10 10 10 10 10 10 10 10 10	16 45.07 2.959 3.564 2382.5	2.959 3.304 2362.5	.304 2362.5	382.5		7.1	N .	720.4	19.0	\ T • 0	4 0 0 P		•
0/0.00 2043.51 29.007 30.575 0.071 0.71 0.71 0.71 0.71 0.71 0.71 0.7	10/0.00 2043.51 29.097 35.573 0.0719 0.5110/0.05 2043.09 29.087 33.574 0.68715 0.110/0.05 2043.08 29.087 34.574 0.68715 0.110/0.05 2043.08 20410 26.573 30.687 0.6854 0.110/0.05 2290.10 26.573 30.767 0.6854 0.110/0.05 2029.58 2618.34 29.669 35.143 0.8440 0.110/0.05 2016.35 29.669 35.133 0.8430 0.110/0.05 2016.35 29.689 35.123 0.8430 0.110/0.05 2016.35 29.689 35.120 0.8430 0.110/0.05 2016.35 29.689 35.120 0.8430 0.110/0.05 2016.35 29.689 35.120 0.8430 0.110/0.05 2016.35 29.689 35.120 0.8440 0.10/0.05 2016.35 29.689 35.120 0.8440 0.10/0.05 2016.35 29.689 35.120 0.8440 0.10/0.05 2016.35 29.689 35.120 0.8440 0.10/0.05 2016.35 29.689 35.120 0.8440 0.10/0.05 2016.35 29.689 35.120 0.8440 0.10/0.05 2016.35 201	10 45.06 2.962 3.300 3382.7	2.962 3.300 2382.7	.300 Z382./	382.7		ر د ب		256.5	99.0	0.20	000		٠, ۱
0.0.28 2043.09 29.087 33.374 0.871 0.70.35 20.45 0.871 0.70.35 20.27 20.27 0.871 0.871 0.871 0.871 0.871 0.871 0.871 0.871 0.871 0.872 0.8	10/0.28 2045.09 29.087 35.5/4 0.6712 0.11 10/10.45 2045.78 29.103 35.5/82 0.8718 0.11 10/10.45 2290.71 26.273 30.682 0.85/4 0.15/10 0.19/10 20.273 30.687 0.85/4 0.11 10/10.45 2299.01 26.271 30.67 0.85/4 0.11 10/10.45 2289.65 26.204 30./41 0.85/24 0.11 9/29.54 2619.08 29.689 35.190 0.8440 0.11 10/10.45/4 0.11 10/10.45	20 45.46 2.981 3.319 2686.3	2.981 3.312 2686.3	.312 2606.3	606.3		•	n•0/n	643.5	00.0	, , ,	1/0	200 T • 10	ĸ.
070.35 2043.78 29.103 33.482 0.871 919.34 2290.70 26.231 30.627 0.856 919.38 2290.10 26.273 30.627 0.855 919.38 2289.65 26.204 30.741 0.852 929.58 2618.34 29.669 32.143 0.844 929.34 2618.08 29.669 32.143 0.844 929.34 2618.08 29.669 32.123 0.844 929.34	1070.55 2045.78 29.103 35.582 0.8718 0.1 919.54 2290.70 26.271 30.627 0.8554 0.1 919.55 2289.65 26.274 30.741 0.8527 0.1 919.58 2618.54 29.669 35.145 0.8440 0.1 929.54 2619.08 29.669 35.195 0.8440 0.1 929.52 2616.55 29.659 35.195 0.8450 0.1	28 45.85 2.981 3.315 2686.4	2.981 3.315 2606.4	.315 2606.4	606.4		4.6	7.0.0	1143-0	80.6	10.0	.8/1	0.100F	ĸ.
19.34 2290.70 26.231 30.627 0.856 19.38 2290.10 26.212 30.767 0.852 19.85 2289.65 26.201 30.741 0.852 29.58 2618.34 29.669 35.143 0.844 29.34 2619.08 29.669 35.123 0.844	919.34 2290.70 26.231 30.627 0.6564 0.1 919.38 2290.10 26.272 30.741 0.6520 0.1 919.48 2618.34 29.669 35.143 0.6440 0.1 929.34 2619.08 29.669 35.193 0.6440 0.1 929.32 2616.35 29.669 35.193 0.8430 0.1	20 45.00 2:032 3.310 2606.8	2:032 3:310 2686.8	.316 2606.8	6.00.8		۸.	070.0	043.7	9.10	ა. ა	.871	0.1008	ĸ.
19.58 2290.10 26.212 30.767 0.652 19.85 2289.65 26.2014 30.741 0.852 29.58 2618.34 29.669 35.143 0.864 29.54 2619.08 29.669 35.193 0.864 50.52 2619.08 29.669 35.193 0.864	919.58 2290.10 26.919 30.767 0.8524 0.1. 919.65 2289.65 26.514 0.8524 0.1 929.58 2618.54 29.669 35.140 0.8441 0.1 929.54 2619.08 29.669 35.190 0.8450 0.1 929.52 2616.55 29.659 35.120 0.8450 0.1	JU 45.02 2.687 2.949 21.66.	2.949 2166.4	.949 2166.4	166.4		5.4	19.5	290.7	6.23	1.62	.856	0.1096 0.000	₹.
19.85 2289.65 26.2014 34.41 4.852 29.58 2618.54 29.669 35.145 4.844 29.54 2619.48 29.669 35.195 4.844 50.50 2616.45 99.44 35.195 4.844	919.65 2289.65 26.504 30.741 0.8524 0.17 929.58 2618.54 29.665 35.145 0.8440 0.1 929.54 2619.08 29.669 35.195 0.8450 0.1 929.52 2616.55 29.639 35.125 0.8459 0.1 929.45 2617.59 29.658 35.140 0.8440 0.1	0.0 45.03 2.791 2.967 2166.0	2.791 2.967 2166-0	.967 2166.0	166.0		5.4	39.5	290.1	6.21	0.76	. 652	0.10%	٣.
29.58 2618.34 29.669 35.145 0.844 29.34 2619.08 29.669 35.193 0.843 50.35 2616.35 29.689 35.193 0.843	929.58 2618.54 29.669 35.145 0.844n 0.1 929.54 2619.08 29.669 35.195 0.845n 0.1 929.52 2616.55 29.639 35.125 0.8439 0.1 929.45 2617.59 29.658 35.140 0.844n 0.1	00 45.02 2.698 2.964 2166.4	2.698 2.964 2166.4	*964 6166.4	166.4		5.4	19.8	289.0	0.50	4.0	.852	6.1.43	₹.
29.54 2619.08 29.669 35.195 0.845 59.55 2616.35 29.25 35.123 0.843	929.34 2619.08 29.669 35.193 0.8430 0.1 929.32 2616.35 29.639 35.123 0.8439 0.1 929.45 2617.59 29.658 35.140 0.844n 0.1	00 45.03 3.193 3.670 2166.8	3-193 3-670 2166.8	.670 2166.8	166.8		5.7	29.5	618.5	9.66	5.14	.844	7671°E	٦,
00.50 0616.45 00 can 30.403 0.843	929.32 2616.35 29.639 35.123 0.8439 0.1 929.45 2617.59 29.658 35.140 0.8440 0.1	00 45.84 3.199 3.679 2166-4	3-199 3-679 <166-4	.679 <166.4	66-4		5.7	29.9	619.0	9.66	9.19	843	0.1291	۲.
CONTRACT AND	929.45 2617.59 29.65R 35.140 0.844n 0.1	ou 45,04 3,191 3,665 7166.	3,191 3,665 7166.	.9917 699.	66.		5.7	29.0	616.	9.63	5.12	. 843	_	۲,
29.45 2617.59 29.658 35.140 0.844		118 45-14 3-193 3-669 2166.	3.669 2166	.667 2166.	99		5.7	29.4	617.	9.65	7.14	. U44	0.1297	۲,

ted Performance Parameters, 4-1/2-Stage Configuration (Concluded), Table I.

| F L U 4 A PAG | 1.58  | 1.58  | 1.58   | 1.19   | 1.19   | 61.  |   |  |   | ٧ .<br>٧ .   | 9   | \$ .<br>N   | 2.<br>5.  | 2.50   
   | 2 × 5  | 1. v=  
   
   | 1.40   | 1 · v   | 1.77  | 1.72  | 1.72   
  | 2.0   | e e  | # C   | 1.4  | 1.4/   | 1.4/  |   | ¥ ,   
   | 1. n4                                 | 1 . 46                                | C . I   | 0       |   | 1.76  | 1.16    |
|---------------|---|---|--|--|--|--|---|--|---|--|---|---|---
--|--
--
--
--|--|---|---|---|---
---|--|---|--|--|---|---
---|---------------------------------------|---------------------------------------|---------|---------|---|---|---------|
| 0.770         | 0.1.64  | 0 · 1 · 0   | 11.1163  | 10.10.54   | 0.100  | 11 - 1 - 54  | 0.1.18  | Ţ.,  | 11.1.11/  | 1555   | 1.00%   | 0.1022  | 0.1.97  | 0.1196   
   | 0.1195   | ٠  
   
   | 267= · =   | 0.070   | 101.  | 101010  | /101.0   
  | 0 - 1 + 0 0   | 8.1405   | C0+1-0  | 6//0.0   | 0.07/5   | 9//8-8  | 2000 en   | ٠   
   | 0.0003                                | /000.0                                | 0.105/  | 000000  | 0.10%   | U - L 0 4   | 1084    |
| ETA 11        | 0.8181  | 0.8173  | 0.8169   | 0.7803   | 0.8/.0   | 0.7801   | 0.8607  | 0.5612   | 1.8607  | 0.8/14   | 0.8715  | 0.8718  | 0.8053  | 0.8045   
   | 0.8045   | 0.7247   
   
   | 0.7248   | 0.7250  | 0.8356  | 0.5349  | 0.8352   
  | 0.8559  | 0.4558   | 0.8564  | 0.0610   | 0.6615   | 0.6620  | 0.6/60  | 96/90   
   | 0.6/54                                | /060.0                                | 0.6911  | 0.6908  | 4.85.55   | 0.8537  | 0.8541  |
| DH1 1 0V      | 34.890  | 34.428  | 34.449   | 34.006   | 34.422   | 34.786   | 35.011  | 35.316   | •   |  | 35.463  | 35.450  | 39.831  | 39.874   
   | 39.483   | 39.320   
   
   | 39.321   | 39.307  | 39.985  | 46.622  | 40.032   
  | 40.208  | 40.207   | 40.197  | 34.592   | 34.552   | 34.542  | 32.588  | 32.010  
   | 32.594                                | 30.552                                | 30.252  | 30.278  | 30.722  | 30.711  | 30.694  |
| он ғах        | 28.544  | 28.548  | 28.550   | 27.150   | 27-160   | 27.135   | 30.393  | 30-415   | 30.419  | 30.880   | 30.005  | 30.917  | 32.074  | 32.080   
   | 32.085   | 28.496   
   
   | 28.502   | 28.496  | 33.412  | 33.414  | 33.434   
  | 34-414  | 34-400   | 34.426  | 22.844   | 22.856   | 22.86R  | 22.030  | 22-031  
   | 22.013                                | 20.895                                | 20.908  | 20.017  | 26.222  | 26.219  | 26.217  |
| ra Eav        | 2841.11   | 2641.20   | 2840-77  | 3874-19  | 3074-35  | 3071.95  | 2401.19   | 2405.98  | 2404.82   | 2187.70  | 2187.49   | 218/.89   | 2831.51   | 2832.87  
   | 2832.83  | 3222.56  
   
   | 3222.17  | 3222.32   | 2644.94   | 2643.83   | 2642.35  
  | 2454-55   | 2456.28  | 2456.75   | 3492.39  | 3490.56  | 3489.58   | 3364.12   | 3363.64   
   | 3364.56                               | 3188.70                               | `       | -       | •   | 2288.61   | 2289.81 |
| WAN EUV       | 848.02  | 84/.04  | 847.93   | 761.53   | /61.53   | 161.04   | 1003.12   | 1004-12  | 1003.73   | 1077.20  | 10/0.79   | 1077.46   | 932.08  | 932.07   
   | 931.89   | 762.67   
   
   | 762.38   | 762.59  | 1009.77   | 1009-89   | 1009-85  
  | 1082.68   | 1085.08  | 1083.20   | 577.40   | 577.17   | 577.94  | 577.64  | 571.42  
   | 577.10                                | 517.17                                | 277.67  | 578.06  | 919.27  | 918.94  | 919.03  |
| WA EUV        | 26.106  | 26.102  | 26.101   | 26.382   | 26.382   | 26.386   | 25.296  | 25.325   | 25.312  | 24.820   | 24.807  | 24.816  | 25.776  | 25.779   
   | 25.775   | 26.390   
   
   | 26.380   | 26.387  | 25.405  | 25.401  | 25.385   
  | 24.971  | 24.986   | 24.983  | 26.686   | 269.92   | 26.685  | 26.688  | 26.680  
   | 26.701                                | 26.682                                | 26.675  | 26.686  | 25.468  | .44   | 25.458  |
| N E · V       | 1949.01   | 1948.90   | 1949.23  | 1731.94  | 1731.90  | 17,51.94   | 2379.30   | 2378.96  | 2379.21   | 2684.89  | 2604.37   | 2605.02   | £169.64   | 2169.33  
   | 2169.29  | 1734.01  
   
   | 1733.99  | 1734.02   | 2384.80   | <345.49   | 2386.84  
  | 2601.51   | 2600.89  | 2601.45   | 1298.22  | 1298.74  | 1299.47   | 1298.6/   | 1298.53   
   | 1298.15                               | 1299.24                               | 1299.34 | 1299.70 | 2166.38   | 2166.51   | 2165.97 |
| P10/P53       | 3.640   | 3.655   | 3.650  | 3.650  | 3.660  | 3.654  | 3.674   | 3.677  | 3.680   | 3.674  | 3.67/   | 3.675   | 4.830   | 4.851  
   | 4.850  | 4.812  
   
   | 4.810  | 4.800   | 4.816   | 4.829   | 4.830  
  | 4.821   | 4.825  | 4.819   | 3.668  | 3+660  | 3.658   | 3.304   | 3.307   
   | 3.305                                 | 2.953                                 | 2.952   | 2.956   | 2.961   | 2.960   | 2.958   |
| P10/P13       | 10  | 16  | 9  | . 5  | 5  | 4  | .21   | .21  | .21   | . 2  | . 23  | 2.3   | 85  | 86   
   | 86   | .77  
   
   | .77  | .77   | 80  | 88  | .83  
  | . 91  | 16.  | .91   | .12  | 1.2  | <u>ب</u>  | .89   | . 9.9   
   | . 89                                  | • 65                                  | .65     | • 65    | 69.   | 69.   | 69.     |
| P 1.0         | 5.  |   | , c  | 3  |  | 5  | 5.1   | 0  | -   | 5.0  | 5.0   | 5.0   | 5   | 5.0  
   |  | 5.1  
   
   | 5  | 5 . 1   | 5.0   | 5.1   | 5.0  
  | -   | 5.0  | 5 . 0   | 5.1  | Ē  | 5.0   | 5.0   | 5.0   
   | e                                     | 0                                     | 0       |         | 0   |   | 5.0     |
| rcl woes      | n 6   | 90  | 2.5  | ت<br>د<br>د  | 3  | . <b>.</b>   | 7 n   | 1 c 6  | 30 T  | 120  | 120   | 17.0  | 991   | 100  
   | ) =<br>-<br>-  | 2 2  
   
   |  | 0 8   | 110   | 110   | 110  
  | 120   | 150  | 120   | 90   | 9.4  | D O   | 0.0   | 9.0   
   | <del>j</del> o                        | o g                                   | рo      | 0.0     | poT   | 100   | 10.0    |
| RDC           | 047   | ) N   | 25.1   | 100  | 753  | 25.5   | 255   | 256  | 257   | 25.E   | 250   | 240   | 261   | 100  
   | 7 6  | 0.00   
   
   | 265  | 266   | 196   | 200   | 569  
  | 271   | 27.1   | 272   | 273  | 274  | 275   | 276   | 277   
   | 278                                   | 279                                   | 280     | 281     | 282   | 283   | 284     |
|               | DG PGT NDES PTO PTO/PT3 PTO/PS3 N EVV WA EQV WAN EWV TO EQV DH FOV DHIOOV ETA 1T U/CU | 0C FCI 1.0ES PIO PIO/PT3 PIO/PS3 N E4V WA EUV WAN EWV TO EQV DH FOV DHI 1.0V ETÀ 17 U/LU FL<br>40 90 45.02 3.162 3.640 1949.01 26.1U6 848.02 2841.11 28.544 34.690 U.8181 U.11.04 | 0C FCI NOES PIO PIO/PT3 PIO/PS3 N ENV WA EUV WAN EUV TO EQV DH FON DHI IQV ETA IT U/LU FL<br>49 90 45.02 3.162 3.640 1949.01 26.106 848.02 2841.11 28.544 34.890 U.8181 U.1164<br>58 90 45.02 3.166 3.655 1948.90 26.102 847.04 2841.20 28.548 34.728 0.8173 0.103 | 00 FCI NUES PIO PIO/PT3 PIO/PS3 N ENV MA EUV MAN EUV IO EOV DH FOV DHI IOV ETA IT U/LU FL<br>49 90 45.02 3.162 3.640 1949.01 26.106 848.02 2841.11 28.544 34.890 U.8181 U.1164<br>50 90 45.02 3.166 3.655 1948.90 26.102 847.04 2641.20 28.548 34.28 0.8173 0.105<br>51 90 45.04 3.169 3.650 1949.23 26.101 647.93 2840.77 28.550 34.949 0.8169 0.1163 | 00 FCT hOES PIO PIO/PI3 PIO/PS3 N ENV MA EUV WAN EUV IO EQV DH FOV DHI 10V ETA 17 U/LU FLA 99 99 45.02 3.162 3.640 1949.01 26.106 848.02 2841.11 28.544 34.890 0.8181 0.1164 50 99 45.02 3.166 3.659 1949.20 26.102 847.04 2841.20 28.548 34.928 0.8173 0.1163 51 89 45.02 3.166 3.659 1949.20 26.101 847.93 2841.77 28.550 34.949 0.8169 0.1163 51 8.0 45.02 3.159 3.659 17.31.94 26.382 761.93 3074.19 27.159 34.806 0.7803 0.1034 | 00 PCI NUES PIO PIO/PI3 PIO/PS3 N ENV MA EUV MAN EUV IO EQV DH FOV DHI 10V ETA 17 U/LU FLA 19 VU 45.02 3.162 3.640 1049-01 26.106 848-02 2841-11 28-544 34-890 U-8181 0-1164 50 VU 45.02 3.166 3.659 1948-90 26.102 847-04 28-11-20 28-548 34-928 0-8173 0-1163 51 VU 45.02 3.166 3.659 1048-20 26.101 647-93 2840-77 28-548 0-8173 0-1163 51 VU 45.02 3.169 3.650 1731-94 26.382 761-93 3074-35 27-150 34-82 0-7800 0-1033 0-1033 | 00 pcl nules pio pio/pis pio/pss n Euv ma Euv man Euv IO Euv DH Fou DHI 10V ETA 17 U/LU PL 49 90 45.02 3.162 3.640 1949.01 26.106 848.02 2841.11 28.544 34.890 U.8181 U.1164 50 90 45.02 3.166 3.659 1948.90 26.102 847.93 2841.20 28.548 34.99 U.8181 U.1164 51 90 45.02 3.169 3.650 1948.20 26.101 848.02 2841.11 28.544 34.99 U.8181 U.1164 52 cu 45.02 3.169 3.650 17.31.90 26.382 761.53 30.74.55 27.160 34.90 U.800 U.10.33 53 cu 45.02 3.151 3.660 17.31.90 26.382 761.53 30.74.55 27.160 34.806 U.7801 U.10.33 54 cu 45.04 3.143 3.654 17.31.94 26.386 761.04 30.71.95 27.135 34.786 U.7801 U.10.34 | 00 FCI LUES PIO PIO/PI3 PIO/PS3 N EUV MA EUV MAN EUV IO EQV DH FOU DHI 10V ETA 17 U/LU FL<br>49 90 45.02 3.162 3.650 1948.90 26.102 847.04 2841.11 28.544 34.890 U.8181 U.1164<br>51 90 45.02 3.166 3.650 1948.90 26.102 847.04 2841.20 28.548 34.928 0.8173 0.1165<br>52 cu 45.02 3.151 3.650 1731.90 26.382 761.03 3074.95 27.150 34.060 0.7803 U.1053<br>53 cu 45.04 3.153 3.151 3.650 1731.90 26.382 761.03 3074.35 27.150 34.060 0.1803<br>54 tu 45.04 3.153 3.153 3.559 1751.94 26.386 761.04 3071.95 27.156 0.7801 0.1163<br>54 tu 45.04 3.143 3.074 2379.30 25.296 1003.12 2401.19 30.393 35.011 U.86d7 0.1.18 | 00 FCI LUES PIO PIO/PI3 PIO/PS3 N EUV MA EUV MAN EUV IO EQV DH FOU DHI 10V ETA 17 U/LU FLU HI LUES PIO PIO/PI3 N EUV MA EUV MAN EUV IO EQV DH 45.02 3.162 3.6540 10949.01 26.106 848.02 2841.11 28.544 34.690 U.8181 U.1163 51 9.0 45.02 3.166 3.6550 1948.90 26.102 847.04 2841.20 28.548 34.99 U.8183 U.1163 51 84.04 3.164 3.165 3.6550 17.31.94 26.382 7.61.03 30.41.9 27.156 34.99 U.8183 U.1163 3.163 | 00 FCI LUES PIO PIO/PT3 PIO/PS3 N E.V MA EUV MAN EUV IO EOV DH FOV DHI 10V ETA 17 U/LU FLU HI U 45.02 3.162 3.6540 1949.01 26.106 848.02 2841.11 28.544 34.690 U.8181 U.8181 U.163 51 9.0 45.02 3.166 3.655 1948.90 26.102 847.04 2.841.11 28.544 34.690 U.8181 U.8181 U.163 51 8.0 45.02 3.164 3.655 1948.90 26.102 847.04 2.841.77 28.556 34.949 U.8184 U.8184 U.1034 5.2 27.150 34.949 U.8180 U.1034 5.2 27.150 34.949 U.8180 U.1034 5.2 27.150 34.949 U.8180 U.1034 5.2 27.150 34.940 U.8180 U.1034 5.2 27.150 34.940 U.880 U.780 U.1034 5.2 2401.19 37.149 3.677 23.78.96 25.225 10.04.12 2405.98 30.415 35.316 U.8607 U.860 U.880 2.379.21 25.312 10.03.73 2404.82 30.410 35.346 U.8860 U.8860 U.1031. | 0.0         FCI NDES         PIO/PIS         N EvV         MA EUV         MAN EUV         IO EUV         DH FOV         DHI 10V         ETA 11         U/cU         FL           49         90         45.02         3.462         3.659         1948.90         26.105         8448.02         2841.11         28.544         34.89         0.8153         0.106           50         90         45.02         3.465         1948.90         26.101         844.04         28.544         34.99         0.8153         0.106           51         90         45.02         3.465         1948.90         26.101         844.04         7         28.548         34.949         0.8153         0.1053           51         60         45.02         1751.94         26.382         761.53         30.74.19         27.150         34.86         0.7803         0.1053           53         60         45.04         1751.94         26.382         761.53         30.74.35         34.786         0.7803         0.1053           54         60         35.660         1751.94         26.382         761.53         30.74.35         37.786         0.7803         0.1053         30.74.35         37.786         0.7803 | 0.0         PCI NUES         PIO/PIS         PIO/PS         N EvV         MA EUV         MAN EUV         IO EUV         DH FOV         DHI 10V         ETA 11         U/col         PIO           49         90         45.02         3.462         3.659         1948.90         26.102         2841.11         28.544         34.890         0.8123         0.103           50         90         45.02         3.462         3.659         1948.90         26.101         847.93         2841.21         28.544         34.949         0.8123         0.103           51         90         45.02         3.464         3.659         1949.23         26.101         847.93         2841.21         28.544         34.949         0.8124         0.103 | 0.0         FCI nDES         PIO/PT3         PIO/PS3         N EuV         HAA EUV         HAA EUV         IO EUV         DH FOV         DH I I I I I I I I I I I I I I I I I I I | 00 гст годе рто ртоуртз ртоурьз и Ечу и на Ечу | 0.0         FCTDES         PIO/PT3         PIO/PD3         N E.V         MA EUV         MAN EUV         IO EQV         DHI 10V         ETA 11         U/cu         FL           49         9.0         45.02         3.462         3.669         1949.01         26.102         848.02         2841.21         28.544         34.690         U/BB1         0.1104           50         9.0         45.02         3.469         26.102         847.04         28.544         34.690         U/BB1         0.1104           51         9.0         45.02         3.469         26.101         847.04         28.544         34.949         0.8173         0.1103           52         0.0         45.02         3.469         26.102         847.04         28.544         34.949         0.8173         0.1103           53         0.0         45.04         17.51.94         26.382         761.03         24.497         0.8103         0.1103           54         0.0         45.04         17.51.94         26.382         761.03         30.499         0.8103         0.1103           55         1.0         45.04         17.51.94         26.382         761.03         30.499         0.8103         0. | 0.0         FCT LOES         PIO/PT3         PIO/PD3         N E-V         MA E UV         MAN E UV         IO E CO         DH FOV         DH I 1 QV         EIA II         U CU U         PIO/PT3         PIO/PT3         N E-V         MAN E UV         IO E CO         DH FOV         DH I 1 QV         DH I 1 QV <td>0.0         FCT LOES         PTO/PT3         PTO/PD3         N E«V         MA EUV         MAN EUV         TO EQV         DH FOV         PTO/PD3         PTO/PD3</td> <td>0.0         FCI 1,0ES         PIO PIO/PIS         N E.V         NA EdV         NAN EdV         TO EdV         DH I 10V         ETA 17         U/LU           49         9.0         45.02         3.162         3.659         1948.01         26.102         844.04         28.544         34.690         0.8173         0.1103           50         9.0         45.02         3.166         3.659         1948.90         26.102         847.04         28.544         34.09         0.8173         0.1103         0.8173</td> <td>0.0.         FOI INDES         PIO/PT3         PIO/PP3         N E<sub>4</sub>V         NAM EuV         FOATILIT         Z8-544         34-69         U - 5116         LO POUR         PIO POU</td> <td>0.0         FGT LOES         PIO/PT3         PIO/PS3         N EaV         NAM EUV         TO E0V         DH FOV         PT LIO           49         90         45:02         3:162         3:650         1948-01         26:102         847-03         28:544         34:09         0.8173         0.1003           51         90         45:02         3:164         3:650         1731-94         26:101         847-03         28:544         34:09         0.8173         0.1003           51         80         45:02         3:151         3:650         1731-94         26:382         761-03         27:150         34:09         0.8173         0.1003           52         10         45:03         26:101         26:382         761-03         37:49         0.8173         0.1003           54         10         3:670         1731-94         26:382         761-03         37:40         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017</td> <td>0.0         FGT LODES         PIO/PTIS         PIO/PTIS         N E-V         MA EUV         NAM EUV         IO EQV         DH I 10 V         ETA II         UNIT 10 V         ETA II           49         VU         45-02         5.162         3.640         1948-01         26-110         844-02         2841-11         28-544         34-69         0.8173         0.1103           51         VU         45-02         3.166         3.650         1731-92         26-1101         2841-77         28-547         34-69         0.8173         0.1103           51         VU         45-02         3.167         3.650         1731-92         26-382         761-25         34-776         0.8173         0.1103           52         CU         45-03         26-382         761-25         3074-19         27-176         34-786         0.7803         0.1103           53         CU         45-03         26-382         761-25         3074-19         26-386         761-25         3074-19         26-189         0.7803         0.1103           54         LU         45-04         3.644         1.04-30         26-186         761-35         3074-19         27-176         34-786         0.7803         0.1110</td> <td>90         91         95, 10, 10, 10, 10         PTO/PT3         N EvV         MA EuV         NAN EuV         10 EuV         DH 1 10V         ETA 11         U. Lot           49         91         45, 10, 2         3.162         3.640         1049-01         26.102         847-93         284-12         285-54         34-929         0.8173         0.110-03           51         90         45, 10, 2         3.165         1.948-90         26.102         847-93         285-54         34-929         0.8173         0.110-03           51         80         45, 10, 2         3.165         2.6110         26.110         26.112         284-12         285-54         34-929         0.8173         0.110-03           52         80         45, 10, 3         3.143         3.650         1.731-94         26.382         761-03         307-15         37-16         37-18         0.110-03           54         80         3.143         3.664         1.731-94         26.382         761-03         307-15         37-180         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780</td> <td>49         γυ         45.02         3.640         1949.01         26.100         вам вы манен         10         регу на 45.02         3.462         3.640         1949.01         26.100         вам вы манен         10         регу на 45.02         3.460         3.650         1948.00         26.102         вам вы манен         26.401.11         28.544         34.690         .0.8173         0.6103         67.03         27.10         28.544         34.690         .0.8173         0.6103         67.03         27.10         28.544         34.690         .0.8173         0.6103         67.03         27.10         28.544         34.690         .0.8173         0.6103         67.03         27.10         28.544         34.690         .0.8174         0.6103         67.03         76.103         27.10         34.690         0.8174         0.6103</td> <td>49         νυ         45.02         3.64°         1040.01         26.10°         beat         10 Eqv         10 H Eqv         bell 100         bell 100</td> <td>49         νυ         45.02         3.640         1049.01         26.106         848.02         2841.11         28.544         96.04 123         10.00         HT 10.0         HT 10.0</td> <td>49         νυ         45-02         3-162         3-640         1040-01         26-110         B48-02         26-110         H E QV         NA E Q QV         NA E QV         NA E Q QV         NA E Q</td> <td>40         VII         FIGURES         PIO/PT3         PIO/PT3         N E.V         HA EUV         HAN EUV         ID E0         DH I I I IV         ETA I II         DH I I I IV         ETA I II         DH I I I IV         PIO PT III         PIO PT IIII         PIO PT IIII         PIO PT IIIII         PIO PT IIIII         PIO PT IIIIII         PIO PT IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII</td> <td>10. FCI LUES PIO PIO/PT3 PIO/PS3 N E-V HA EUV HAN EUV IO EOV DH FOV DHII 10 V ETA II U.V.U HE LUX HAN EUX LIBERTA STATES DIO/PS3 N E-V HA EUV HAN EUX IO EGA 28-51 STATES DIAGN STATES DIA</td> <td>40         VI         45-02         PIO/PET         PIO/PET<td>  10   10   10   10   10   10   10   10</td><td>  10   10   10   10   10   10   10   10</td><td>  10</td><td>  10</td><td>  Feb.   Feb.  </td><td>  Fig. 10   Fig. 2   Fig. 3   Fig. 4   Fig. 6   Fig. 6  </td><td>  10</td></td> | 0.0         FCT LOES         PTO/PT3         PTO/PD3         N E«V         MA EUV         MAN EUV         TO EQV         DH FOV         PTO/PD3         PTO/PD3 | 0.0         FCI 1,0ES         PIO PIO/PIS         N E.V         NA EdV         NAN EdV         TO EdV         DH I 10V         ETA 17         U/LU           49         9.0         45.02         3.162         3.659         1948.01         26.102         844.04         28.544         34.690         0.8173         0.1103           50         9.0         45.02         3.166         3.659         1948.90         26.102         847.04         28.544         34.09         0.8173         0.1103         0.8173 | 0.0.         FOI INDES         PIO/PT3         PIO/PP3         N E <sub>4</sub> V         NAM EuV         FOATILIT         Z8-544         34-69         U - 5116         LO POUR         PIO POU | 0.0         FGT LOES         PIO/PT3         PIO/PS3         N EaV         NAM EUV         TO E0V         DH FOV         PT LIO           49         90         45:02         3:162         3:650         1948-01         26:102         847-03         28:544         34:09         0.8173         0.1003           51         90         45:02         3:164         3:650         1731-94         26:101         847-03         28:544         34:09         0.8173         0.1003           51         80         45:02         3:151         3:650         1731-94         26:382         761-03         27:150         34:09         0.8173         0.1003           52         10         45:03         26:101         26:382         761-03         37:49         0.8173         0.1003           54         10         3:670         1731-94         26:382         761-03         37:40         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017         0.8017 | 0.0         FGT LODES         PIO/PTIS         PIO/PTIS         N E-V         MA EUV         NAM EUV         IO EQV         DH I 10 V         ETA II         UNIT 10 V         ETA II           49         VU         45-02         5.162         3.640         1948-01         26-110         844-02         2841-11         28-544         34-69         0.8173         0.1103           51         VU         45-02         3.166         3.650         1731-92         26-1101         2841-77         28-547         34-69         0.8173         0.1103           51         VU         45-02         3.167         3.650         1731-92         26-382         761-25         34-776         0.8173         0.1103           52         CU         45-03         26-382         761-25         3074-19         27-176         34-786         0.7803         0.1103           53         CU         45-03         26-382         761-25         3074-19         26-386         761-25         3074-19         26-189         0.7803         0.1103           54         LU         45-04         3.644         1.04-30         26-186         761-35         3074-19         27-176         34-786         0.7803         0.1110 | 90         91         95, 10, 10, 10, 10         PTO/PT3         N EvV         MA EuV         NAN EuV         10 EuV         DH 1 10V         ETA 11         U. Lot           49         91         45, 10, 2         3.162         3.640         1049-01         26.102         847-93         284-12         285-54         34-929         0.8173         0.110-03           51         90         45, 10, 2         3.165         1.948-90         26.102         847-93         285-54         34-929         0.8173         0.110-03           51         80         45, 10, 2         3.165         2.6110         26.110         26.112         284-12         285-54         34-929         0.8173         0.110-03           52         80         45, 10, 3         3.143         3.650         1.731-94         26.382         761-03         307-15         37-16         37-18         0.110-03           54         80         3.143         3.664         1.731-94         26.382         761-03         307-15         37-180         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780         0.780 | 49         γυ         45.02         3.640         1949.01         26.100         вам вы манен         10         регу на 45.02         3.462         3.640         1949.01         26.100         вам вы манен         10         регу на 45.02         3.460         3.650         1948.00         26.102         вам вы манен         26.401.11         28.544         34.690         .0.8173         0.6103         67.03         27.10         28.544         34.690         .0.8173         0.6103         67.03         27.10         28.544         34.690         .0.8173         0.6103         67.03         27.10         28.544         34.690         .0.8173         0.6103         67.03         27.10         28.544         34.690         .0.8174         0.6103         67.03         76.103         27.10         34.690         0.8174         0.6103 | 49         νυ         45.02         3.64°         1040.01         26.10°         beat         10 Eqv         10 H Eqv         bell 100         bell 100 | 49         νυ         45.02         3.640         1049.01         26.106         848.02         2841.11         28.544         96.04 123         10.00         HT 10.0         HT 10.0 | 49         νυ         45-02         3-162         3-640         1040-01         26-110         B48-02         26-110         H E QV         NA E Q QV         NA E QV         NA E Q | 40         VII         FIGURES         PIO/PT3         PIO/PT3         N E.V         HA EUV         HAN EUV         ID E0         DH I I I IV         ETA I II         DH I I I IV         ETA I II         DH I I I IV         PIO PT III         PIO PT IIII         PIO PT IIII         PIO PT IIIII         PIO PT IIIII         PIO PT IIIIII         PIO PT IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII | 10. FCI LUES PIO PIO/PT3 PIO/PS3 N E-V HA EUV HAN EUV IO EOV DH FOV DHII 10 V ETA II U.V.U HE LUX HAN EUX LIBERTA STATES DIO/PS3 N E-V HA EUV HAN EUX IO EGA 28-51 STATES DIAGN STATES DIA | 40         VI         45-02         PIO/PET         PIO/PET <td>  10   10   10   10   10   10   10   10</td> <td>  10   10   10   10   10   10   10   10</td> <td>  10</td> <td>  10</td> <td>  Feb.   Feb.  </td> <td>  Fig. 10   Fig. 2   Fig. 3   Fig. 4   Fig. 6   Fig. 6  </td> <td>  10</td> | 10   10   10   10   10   10   10   10 | 10   10   10   10   10   10   10   10 | 10      | 10      | Feb.   Feb. | Fig. 10   Fig. 2   Fig. 3   Fig. 4   Fig. 6   Fig. 6 | 10      |

Reduced Test Data and Calculated Performance Parameters, 4-Stage Configuration. Table II.

FLOWANG	28.K7 28.K4 28.K8		W W	M 4	000	. r.	2.0	0.0	0	. 7	60 G			9.0	χ. «C	2.8	6	9	5	ເກີນ ເຂົ້ອ		7.1		. 7	7			ָר א מילי	2	3.7	3.7	י יי	C 16	4
07/0	0.1377		77	7.	0.1370	7 🙃	0-1514	7	4 7	-	0.1375	7		75	0.1593	-	7	77	7	0.0878	7	-	7.7	7	~	٠, ۱		,	-	7	Ψ.	- F	0.000	1 6
ETA 11	0.8522		.831	844	846	.861	0.8413	.871	.869	.852	0.8517	857	•856	858	0.8726	.870	.867	.867	.705	0.7103	848	848	707	0.8467	.772	822	- 4	861	865	.859	859	407	70	797
DH1 FOV	30.643	30-137	30.453	30-447	31.021	31.329	31.277	31.459	31.512	30.791	30.792	28-175	28.200	28.178	28.364	28.393	28.748	28-801	27.278	27.127	36.839	30.883	30.054 40.054	30.962	35.974	24.058	24.00 AAA	24.686	24.594	24.798	24.797	24.868	201.01	18-146
DH EOV	26.284 26.246 26.275	24.088 24.102	25-314	25-335	26.258	26.989	26.955	27.412	27 - 393	26-250	26.226	24-170	•	• •	. 4	•	•	. •	0	0.0		<b>VO</b> 1	0 Y	, ,	•	0	<b>~</b> •	4 *		_	~	(**)	7	T T
T0 E0V	2286.05 2284.72 2286.63	9 0	5.4		2276-19												704	90/	881	2898.31	275	284	100	266	025	178	1,4	777	783	403	402	20,00	4 -	1
HAN EUV	30.30	758.74		Q 3	J 4		994.65	9	1052.27	918-59	918.64	907.53	21.906	907.53	977.28	975.93	1034.47	1035.33	578.62	582.63	914.01	915.70	320.01 848.01	•	10	740.07	2 4	2 2	884.13			•	oo	90
MA EOV	א מו מו מו	2 % 2	10.10	10 10	10.10	. +	25.027	÷.		Š	in in	, IO	16.1	, 4	24.623	÷	יו פא	. P	w	26.601	, 45	LC U	n 1	3 100	$\sim$	ם א			•	P	~	~	<b>=</b> c	0 - 1 - 4
N ELV	2172.93 2171.83 2172.32	733	1952.02	1952-98	2166.98	2384.58	2384.56 2385.32	2601-11	2600.74	2167.36	2167.58	2167-19	2168.02	2167.97	2381.36	2382-14	2598.45	2604.28	1312.06	1314,16	2165.16	2164.50	10.0012	21/1-10	2171.86	1730.76	2168.17	2168.55	2168.27	2601.52	2601.71	2601.09	2653.31	2653.61
PT0/PS3	3.074 4.00.5	3.081	3.082	3.104	3.097	3.068	3-157	3.083	3.080	3.071	3.071	2.699	2.701	2.69%	2.694	2.697	2.710	2.715	2.712	2.697	3.074	3.083	0.0/0	3.091	3.466	2.298	2.297	2.312	2.305	2.291	2.291	2.290	1.784	1.782
P10/P13	2.706 2.706 2.706	53	19.	.73	.72	.75	.83	777	.7.	.70	.70	. 5	£.	• 4.5	47	.47	•50	.51	.37	36	70.	.7	0 0	.72	• 05	12		\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	16	.17	.17	• 18	9 6	7.3
P 10	45.05 44.99 44.99	500	5.0	0.00	5,2	5.0	٠ ،	5.1	5.2	5.1	5.00	5.1	5.1	2 .	5.0	5.0	5.1	5.2	5.3	40	5.5	5.2	e a	5.0	0.8	. O . (		1	4.9	4.9	4.9	5.0	7 . 4	4.5
PCT NDES	0001	) 0 0 0 0	0 0 0 6	00	100	· 🗝		No	ı o	=	96	9	-	<b>-</b>	4	<b>~</b>	O. S	S	0	9 9	000	007	<b>5</b> 6	<b>&gt;</b> =	=	<b>0</b> 9	<b>3</b> =		_	N.	N/	N. C	VO	122
RDG	4000	, ao o	11	12	4 4	16	17 18	19	21	22	23	25	26	20.0	53	30	31.	0 K)	34	13 to 16	37	38	ى د د	<b>₩</b>	42	4 . 5 .	4 4	4	4.8	49	ر ص	T.	N K	5.4

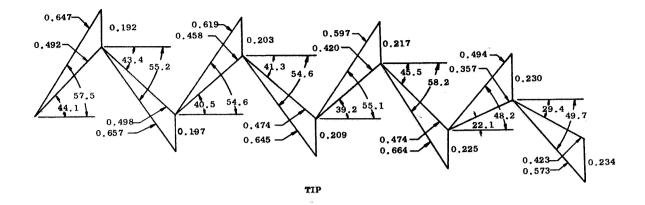
Tabl	e II.	Reduced	Test	Data and	Calculated		Performance P	Parameters	s, 4-Stage	ge Confi	Configuration	(Concluded)	nded).
- 50%	PCT NUES	p10	PT0/PT3	P10/PS3	N EoV	WA EDV	WAN EUV	10 500	DH FOV	UHI FOV	ETA TT	6/10	FLOWANG
ינ	1.02	9	. 7.9	1.757	207.8	21.820	802.93	1117.12	15.912	17.054	0.8617	11.1902	64.6
7 4	1 2 2	.00		1.765	2207.76	21.742	800.01	1113-93	15.222	• 79	0.8556	0-1094	9.57
57	102	. 10	.70	1.758	2207.29	21.929	806.72	1127.79	15.277	17.655	0.8653	0.1900	10.45
ž,	102	9	7.2	1.772	2207.52	21.976	808.55	1143.33	15.455	. A8	0.8641	0.1088	9.53
9	19	6	.71	1.770	1765.86	23.516	692.11	1490.41	15.061	17.694	0.8512	0.1208	22.02
. 19	41	6	.70	1.775	1766.31	23.527	66.269	1490.77	15.062	17.676	0.8521	0.1509	22.12
1 19	10	6	.65	1.737	1326.84	25.798	7.0	1967-69	13.619	10.034	0.8188	0.1154	29.05
64	61	-	.70	1.78/	1327.01	25.072	554.52	1912.45	13.622	17.510	0.7779	0.1127	29.03
. 50	0.1		96.	2.165	1327.00	28.268	625.20	2770-15	17.500	21.805	0.8026	0.0991	34.43
\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	61		66	2.195	1327 • 03	27.840	615.75	2727.84	17.498	22.239	0.7868	0 • 0 • 82	34.54
2.9	01		9	2.313	1326.98	26.440	584.75	2591.06	17.500	23.749	0.7369	0 - 0 2 5 5	34.43
, e	-		. 7.0	3.076	2168.23	25.443	919.42	2287.58	26.235	30.822	0.8512	0-1574	28.79
9 0	, =		. 7	3.079	2167.14	25.483	920-41	2291.68	26.227	30.832	0.8507	0.1573	28.78
				3.079	2165.87	25.451	918-72	2290.79	26-235	30.837	0.8507	0.1.72	28.80
7.0	100	•	. 6	3.067	2170,72	25.488	922.13	2295.43	26.308	30.732	0.8560	0.1377	29.15
7.2		1	.68	3.154	2170.52	25.598	926.01	2305-14	26-304	30.618	0.8591	0.13/9	29.14
7.7	- =	8	.74	3.126	2170.70	25.011	904.90	2252-73	26.31.1	31.240	0.8422	0.1567	29.14
77	30	6	.85	3.486	1735.71	26.333	761.77	2882.48	25.569	32.216	0 - 7937	0.1652	35.79
: A	Ð	6	.85	3.485	1735-33	26.344	761-93	2884.12	25.567	32.208	0.7938	0.1422	35.79
79	e e		.84	3.485	1733.86	26.428	763.71	2894.60	25.556	32.169	0 - 7944	0.1651	35.78
. 69	=	•	96.	3.503	2166.47	25.600	924.05	2470.30	28-133	33.192	0.8476	0.1311	30.70
9.0	100		.94	3.483	2167.10	25.754	930.18	2486.46	28.157	33.04	0.8522	0.1314	30.49
60	0	0	.89	3.431	2166.42	26.214	946.52	2531.38	28-153	32.627	0.8629	0.1520	30.66
1 10	- N	•	• 03	3.500	2598.93	24.674	1068.77	2085.98	29.568	33.824	0.8742	0.15/3	26.37
8	N	•		3.502	2599.61	24.683	1069.44	2086.68	29.575	33.830	0.8/42	0.15/4	26.36
85	N	6	• 03	3.505	2599.43	24.671	1068.64	2086-69	29.588	33.853	U • 8 / 40	0-15/5	20.36
90	9	۵.	5.	5.192	2168,96	25.754	936.99	2792.44	31.648	37.780	6.63/7	0.11/6	37.13
87	-	6	.54	5.200	2168.92	25.758	931-13	2795-43	31.676	37.797	0.8380	0.11/5	36.08
80	-	=	.54	5.191	2169.06	25.765	931-42	2798.96	31.710	3/.777	0.8394	0.11/6	0/.00
68	N	-	.74	5.199	2601.45	24.959	1082-14	2418.51	33.923	39.699	9/98-8	1,1	33.55
9.0	N		.74	5.205	2600.46	24.952	1081.46	2418.95	3.97	39.116	0.8673	0.1409	33.55
è.	0		.73	5.186	2601.73	24.949	1081.85	2416.38	33.910	39.065	0.8680	0-1411	33.55
6	30	9	36	4.987	1732,89	26.374	761.72	3182.56	28-141	36.454	0.7719	0 - 0 9 4 9	38.98
16	80		35	4.978	1732.98	26.369	761.01	3181.91	28-142	•	0.7722	0.044 0.044	38.29
9.6	90	=	36	4.976	1733.11	26.371	1.7	180.	8.13	36.438	0.7721	0.0440	38.28
95	- =	<u>ب</u> *	.79	3.077	168	25.434	S.	2297.28	26.358	<b>Σ</b>	0.8548	`; `	26.79
6	001	45.09	2.707	3.076	2168.12	25.451		2298.33	26.349	30.826	0.8548	3 1	28.79
97	9	-	. 70	3.077	2143.45	25.486	4	2317.91	•	8.9	0.8513	U-1328	28. R.O

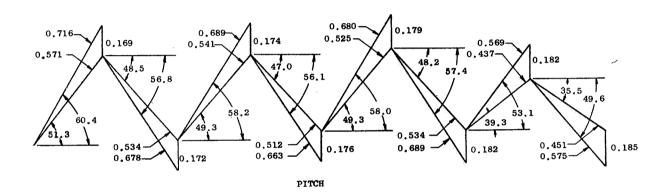
Comparison of Predicted and Experimentally Observed Blade Natural Frequencies with Fixed-Fixed End Conditions. Table III.

	Fire	First Flex	Second	Second Flex	First Torsion	rsion
Stage	Predicted	[mental	Predicted	Experimental	Predicted	Experimental
2000						
-	*	*	*	*	4103	4590
1 6	*	*	*	*	3308	3522
7 (	0.00	7652	*	*	2443	2380
m	CTAC	7 0	7007	5008	2118	2314
7	2034	8/07	7664			
1	tromency search.	nency search.				v.
Apove	tatt to norgan	The farmer				

Table IV. Fatigue Endurance Test Results.

Stage	Cycles to Failure At Failure Stress	Failure Stress KSIDA
Н	750000	08
2	436000	110
æ	434000	110
7	275000	130





Numbers Shown on Velocity Diagrams are Angles in Degrees and Mach Numbers

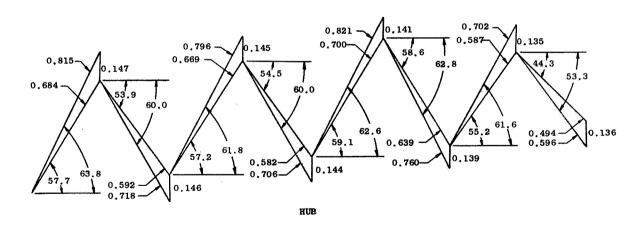


Figure 1. Turbine Design Velocity Diagrams.

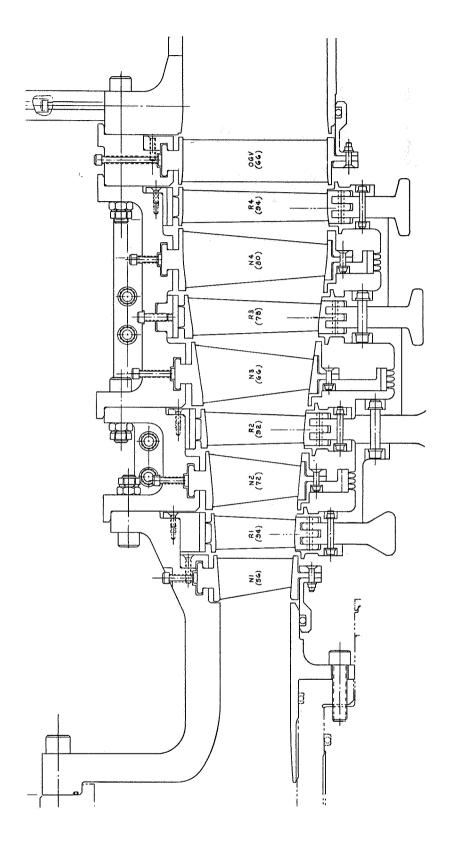


Figure 2. Four and One-Half-Stage Turbine Flowpath.

Figure 3. Four Stage Turbine Rotor Assembled.



Figure 4. Stage One Rotor Assembled.

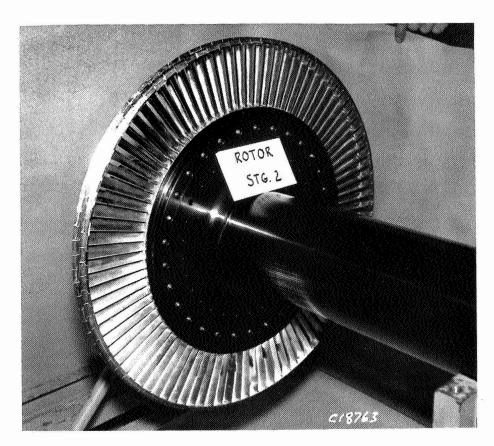


Figure 5. Stage Two Rotor Assembled.

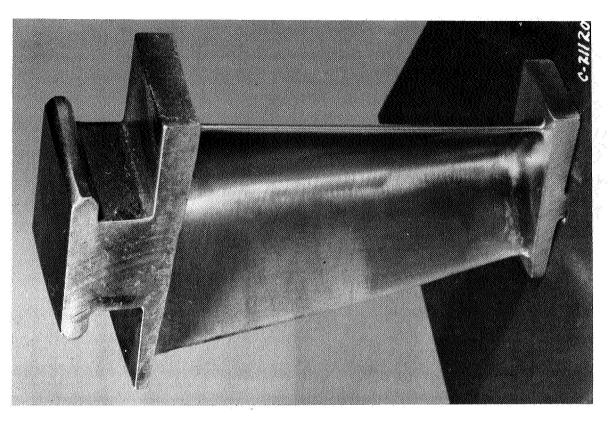


Figure 6. Stage Three Rotor Assembled.



Figure 7. Stage Four Rotor Assembled.

Figure 9. Stage Two Stator.



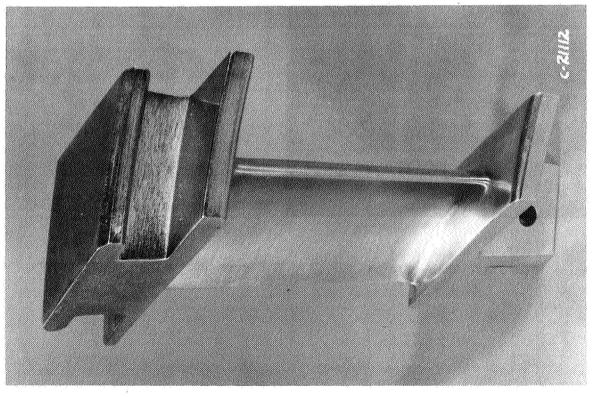
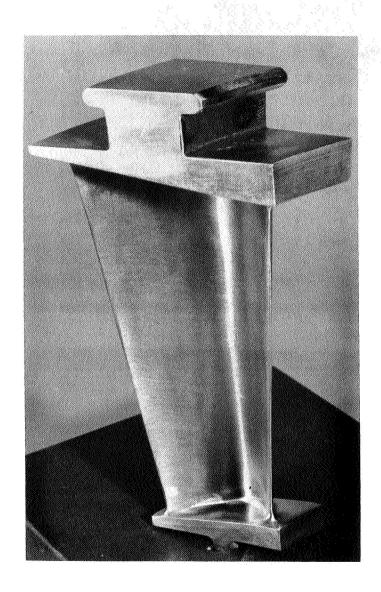


Figure 8. Stage One Stator.



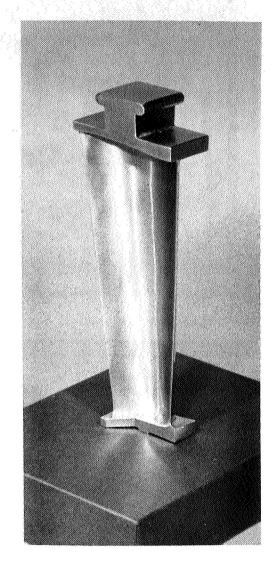


Figure 10. Stage Three Stator.

Figure 11. Stage Four Stator.

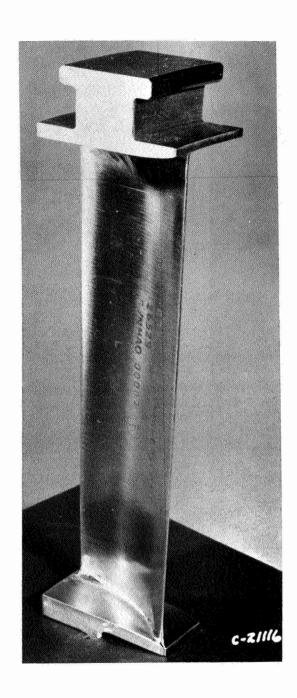


Figure 12. Outlet Turning Vane.

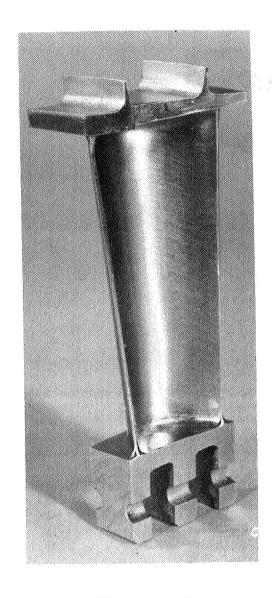


Figure 13. Stage One Rotor.

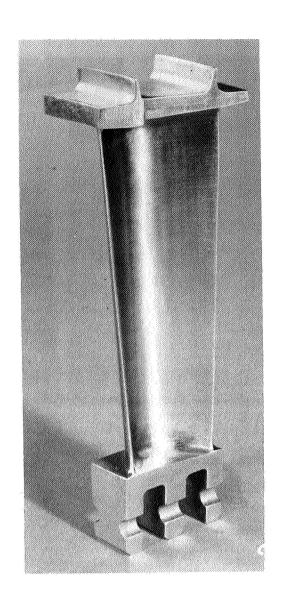
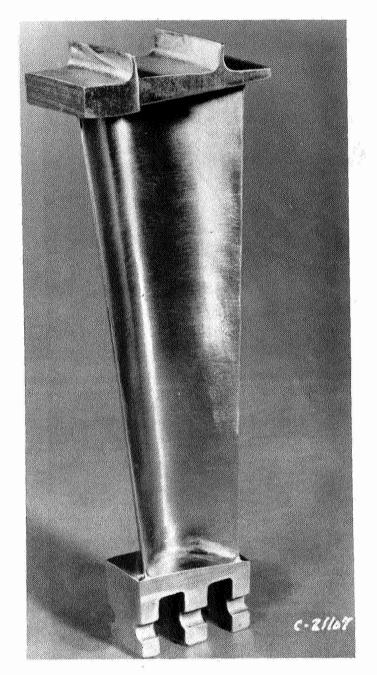


Figure 14. Stage Two Rotor.



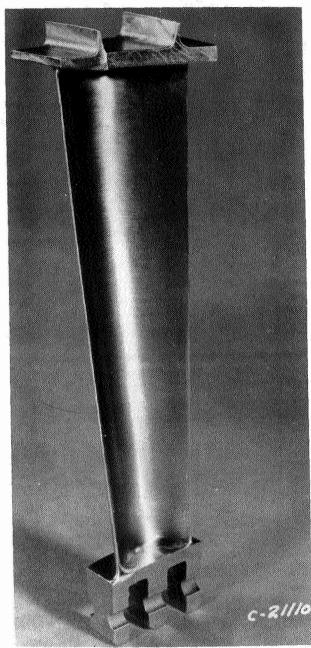


Figure 15. Stage Three Rotor.

Figure 16. Stage Four Rotor.

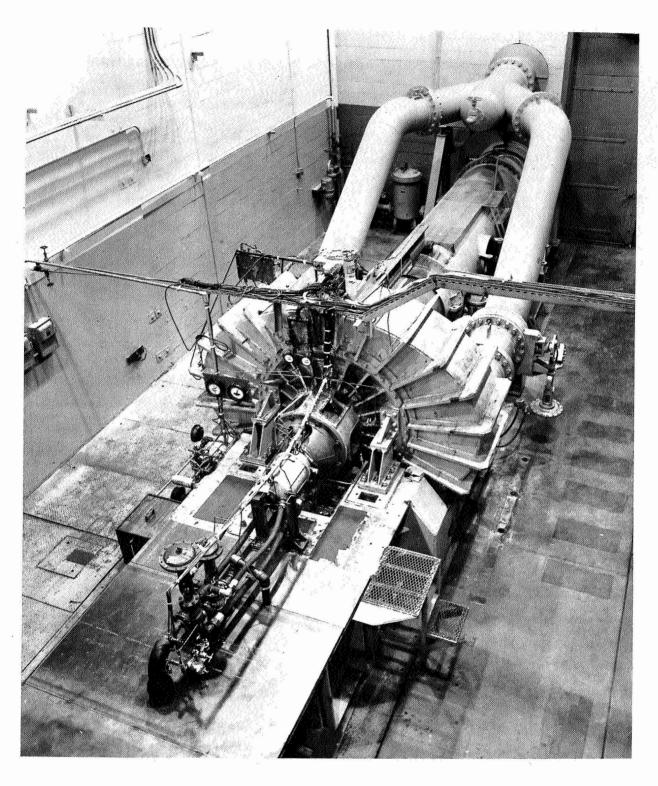


Figure 17. Typical General Electric, Evendale, Air Turbine Test Facility Configuration.

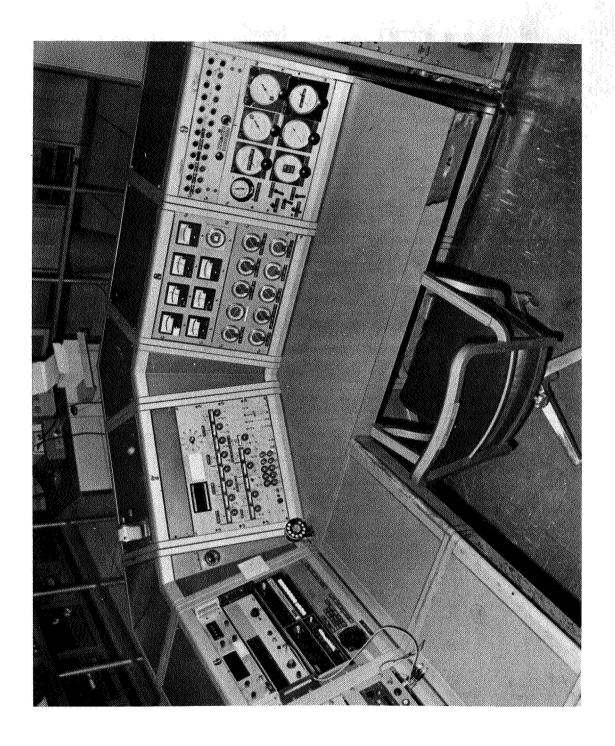


Figure 18. Turbine Facility Control Console.

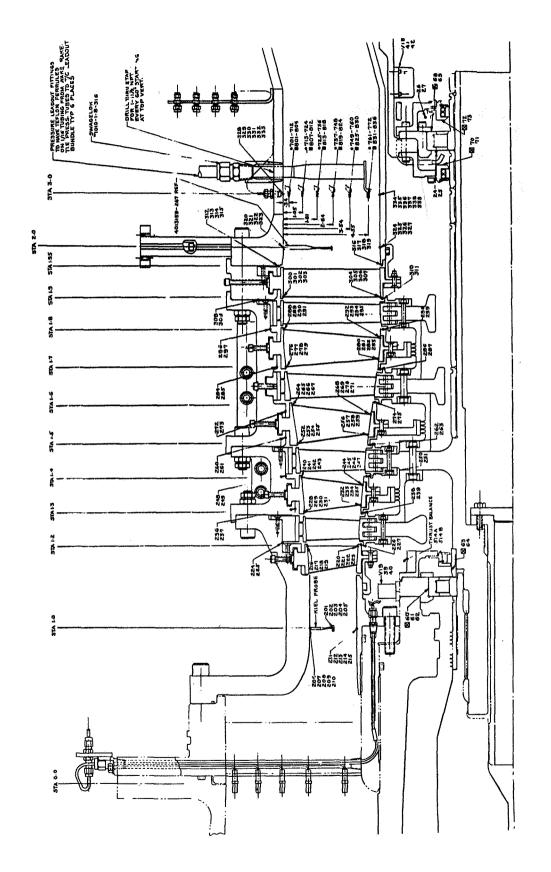


Figure 19. Air Turbine Test Instrumentation.

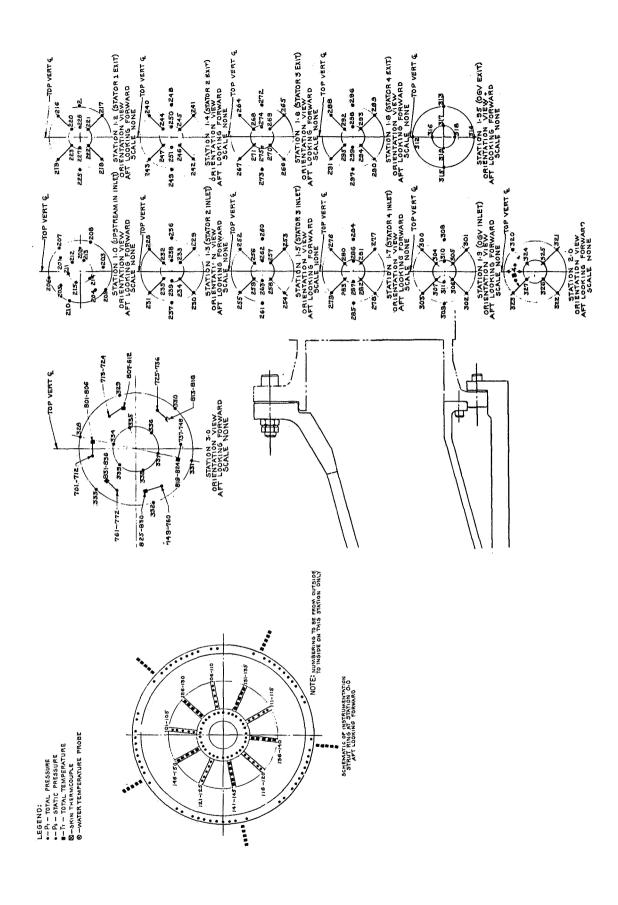


Figure 19. Air Turbine Test Instrumentation (Concluded).

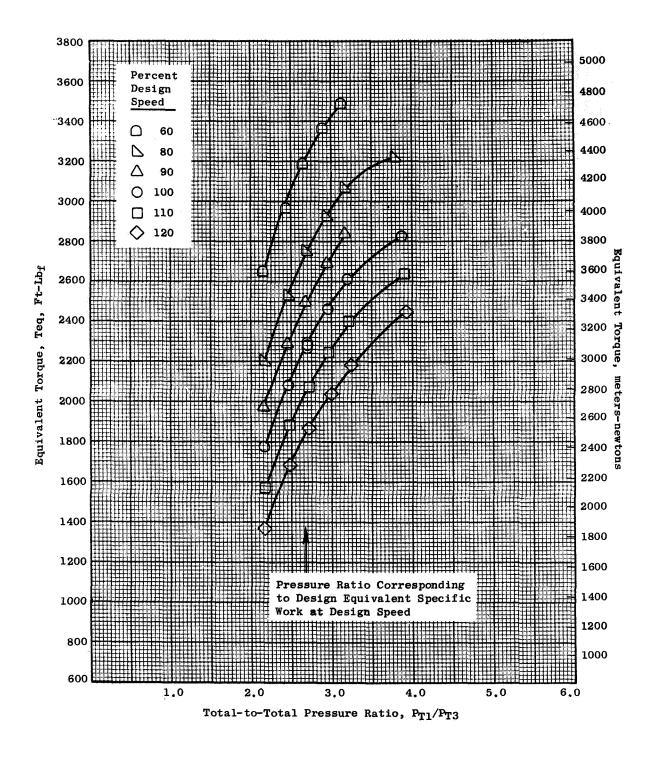


Figure 20. Equivalent Torque Vs. Total-to-Total Pressure Ratio.

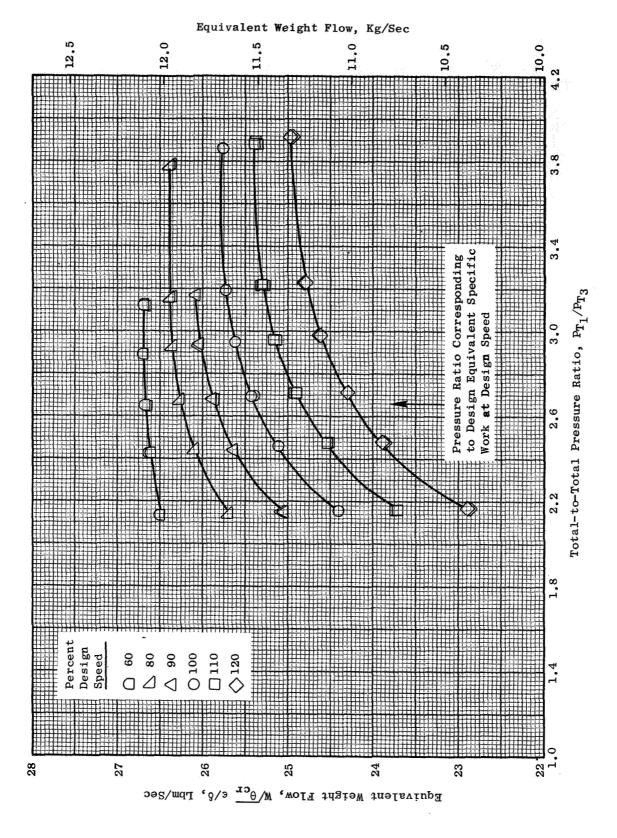
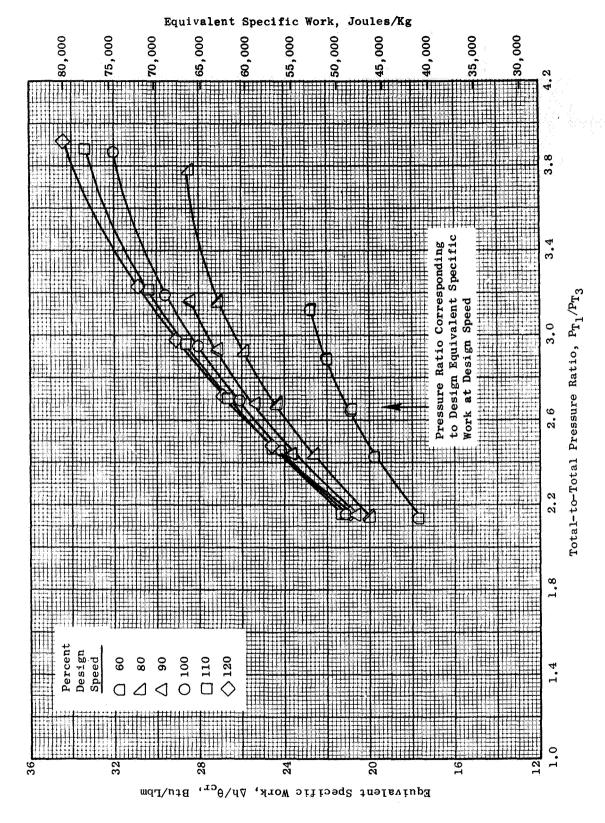


Figure 21. Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio.



Equivalent Specific Work Vs. Total-to-Total Pressure Ratio.

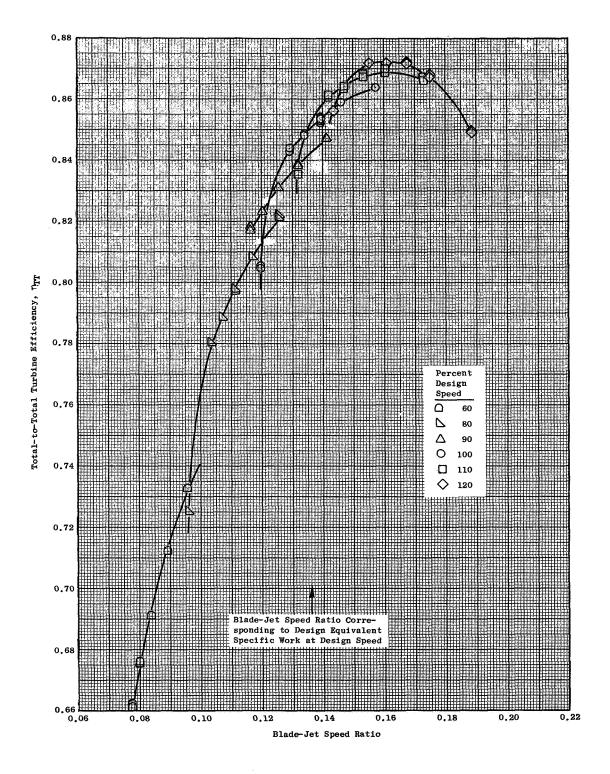


Figure 23. Total-to-Total Efficiency Vs. Blade - Jet Speed Ratio.

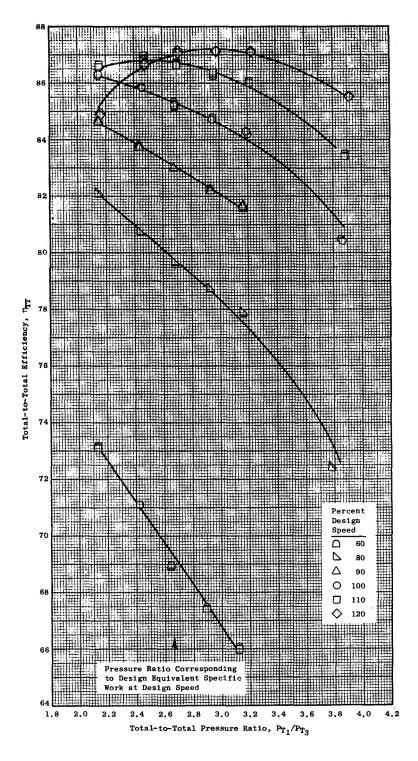


Figure 24. Total-to-Total Efficiency Vs.
Total-to-Total Pressure Ratio.

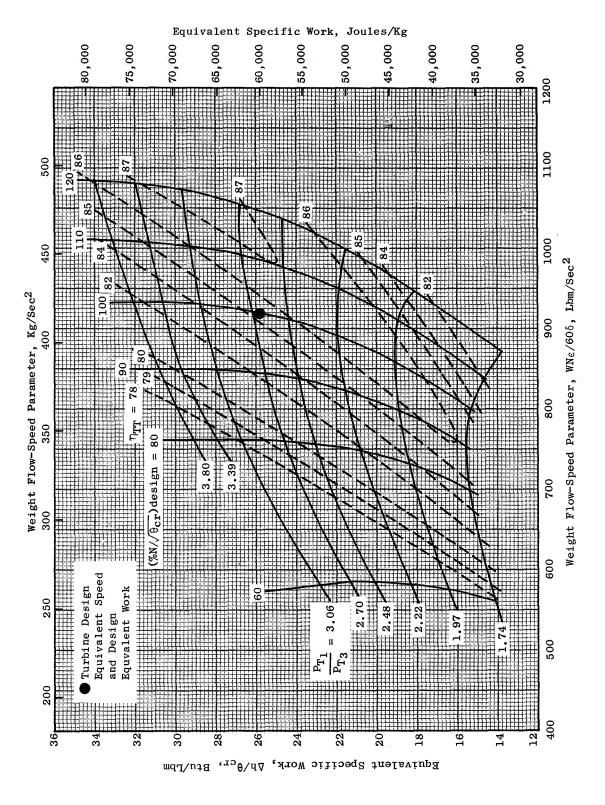


Figure 25. Equivalent Specific Work Vs. Weight Flow-Speed Parameter.

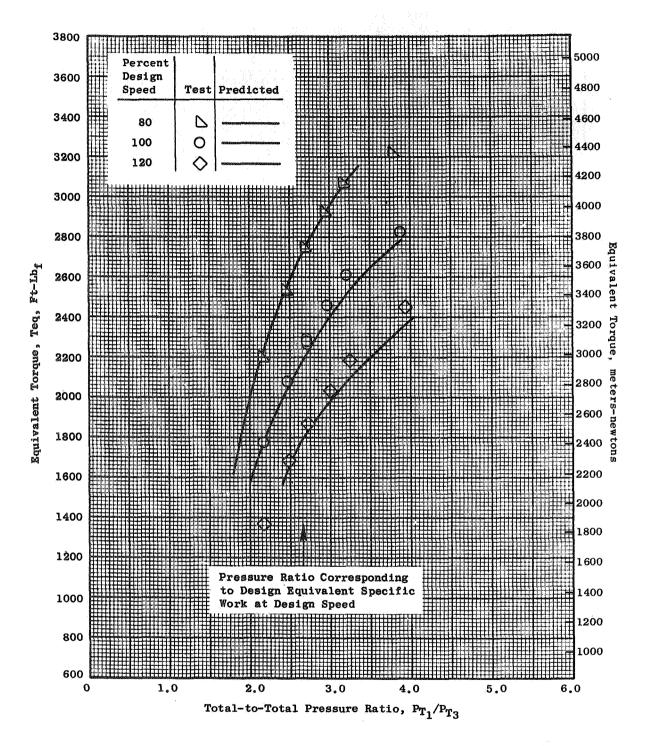


Figure 26. Predicted and Actual Equivalent Torque Vs. Total-to-Total Pressure Ratio.

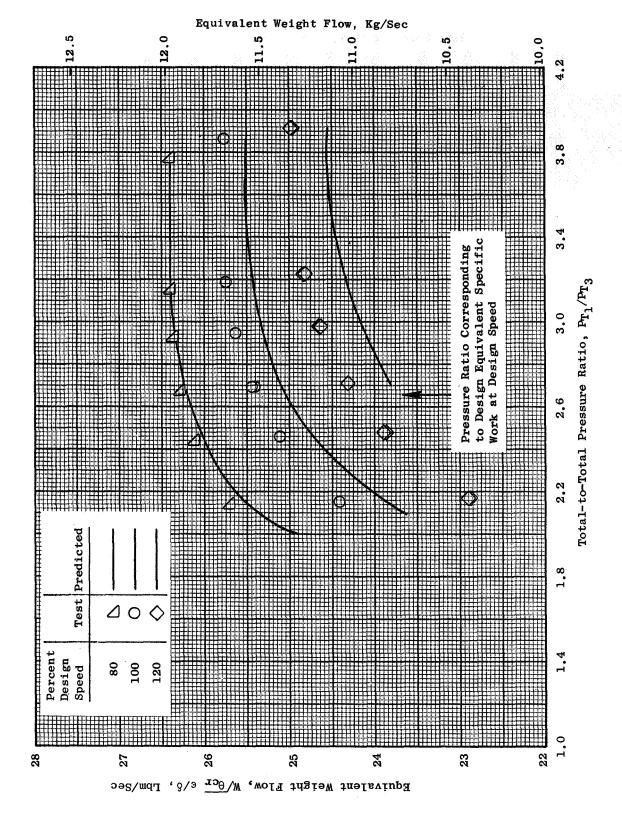
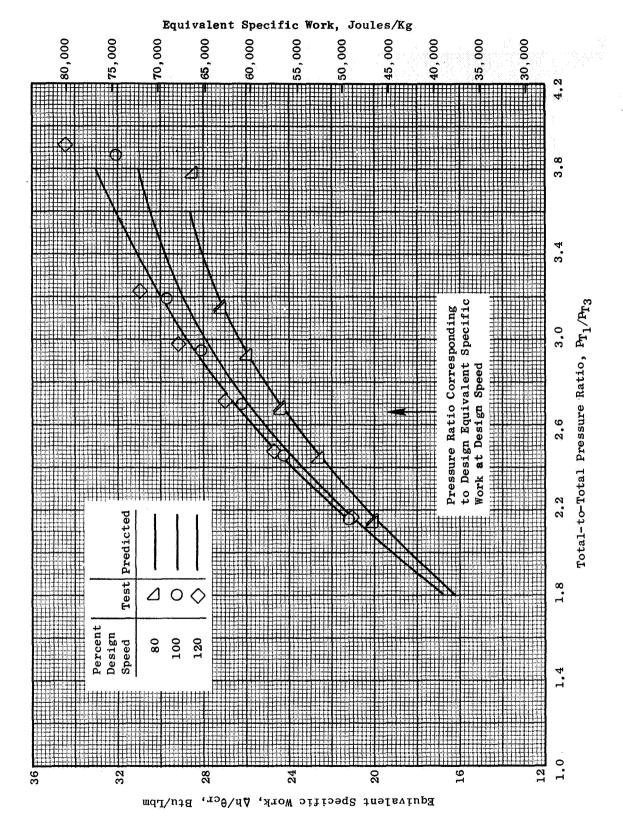


Figure 27. Predicted and Actual Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio.



Predicted and Actual Equivalent Specific Work Vs. Total-to-Total Pressure Ratio. Figure 28.

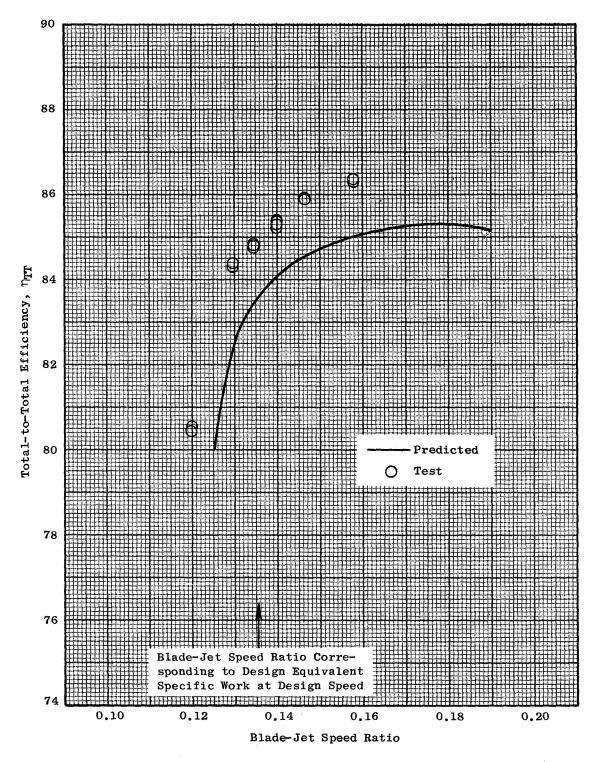


Figure 29. Predicted and Actual Total-to-Total Efficiency Vs. Blade - Jet Speed Ratio, at Design Speed.

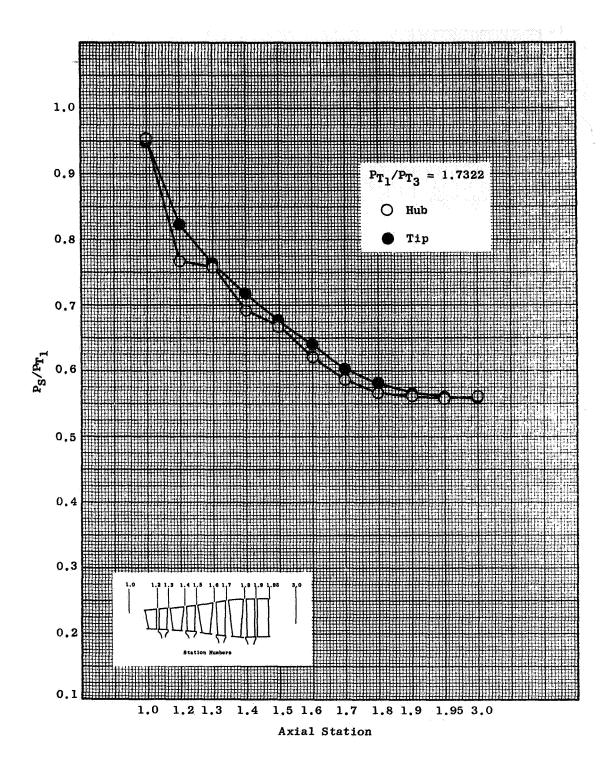


Figure 30. Normalized Static Pressure Vs. Axial Station, at Design Speed.

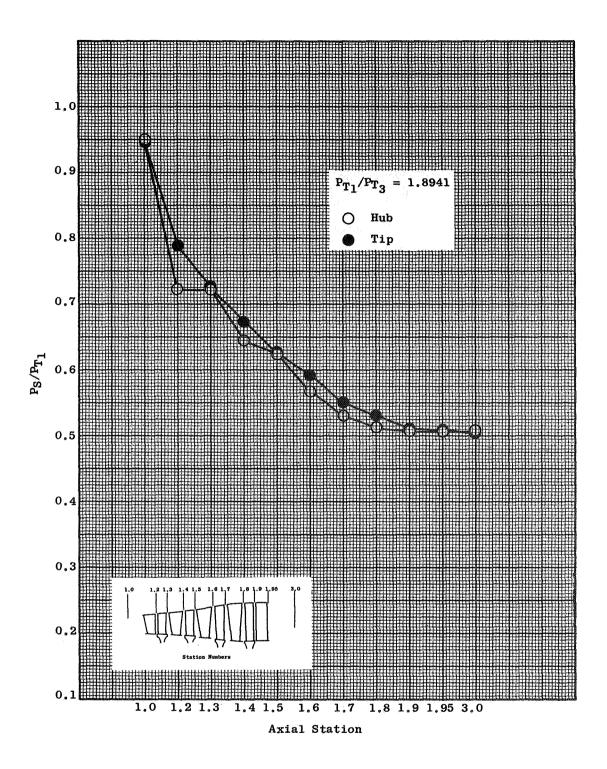


Figure 30. Normalized Static Pressure Vs. Axial Station, at Design Speed (Continued).

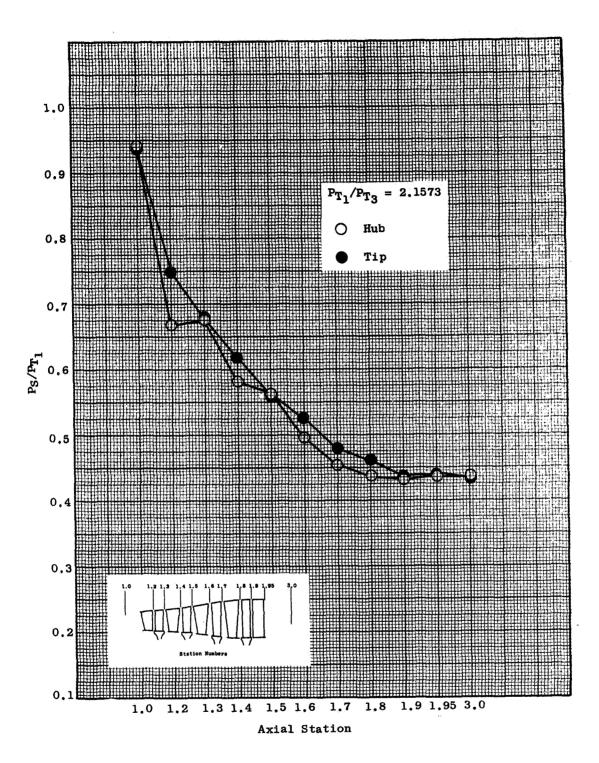


Figure 30. Normalized Static Pressure Vs. Axial Station, at Design Speed (Continued).

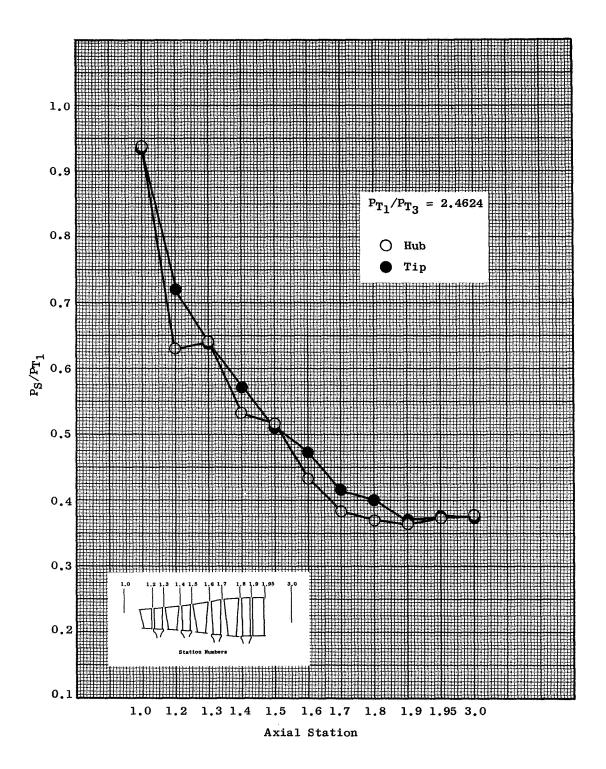


Figure 30. Normalized Static Pressure Vs. Axial Station, at Design Speed (Continued).

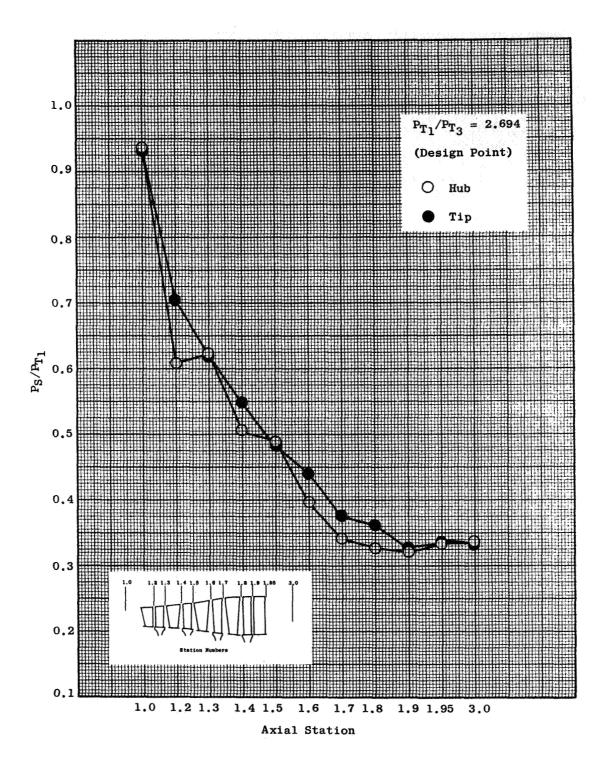


Figure 30. Normalized Static Pressure Vs. Axial Station, at Design Speed (Continued).

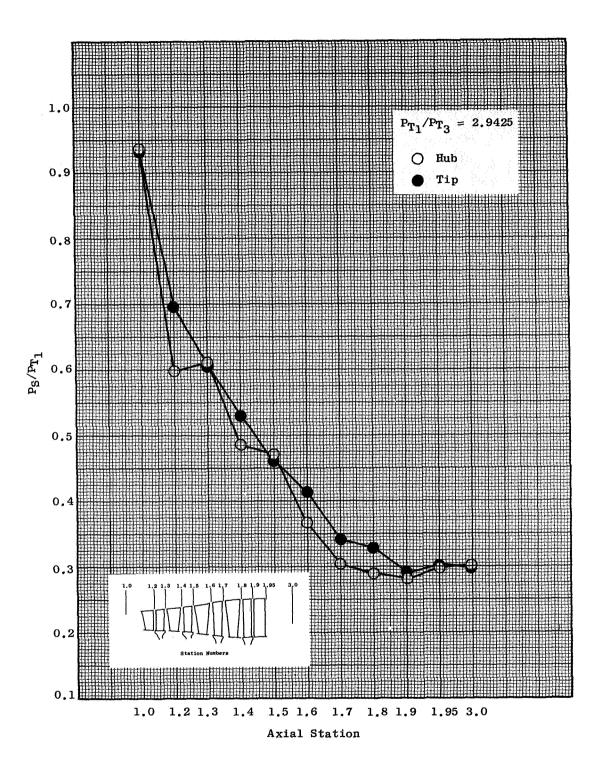


Figure 30. Normalized Static Pressure Vs. Axial Station, at Design Speed (Continued).

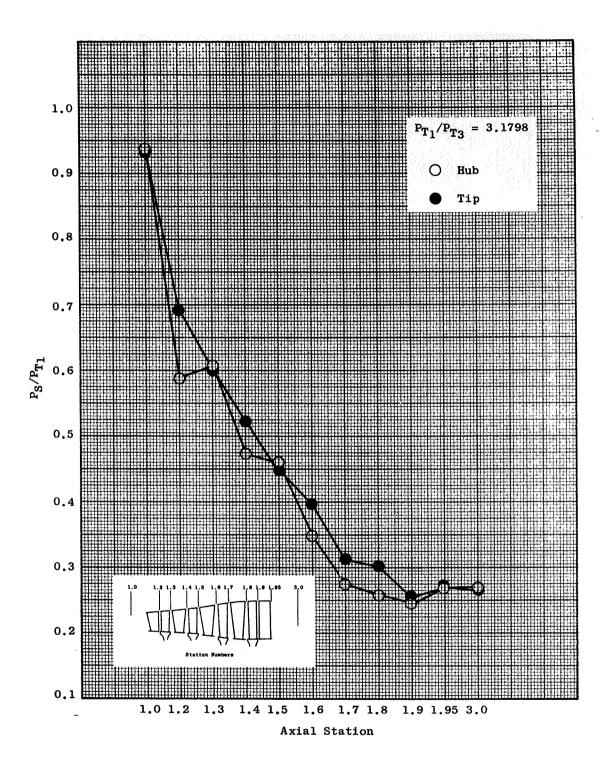


Figure 30. Normalized Static Pressure Vs. Axial Station, at Design Speed (Continued).

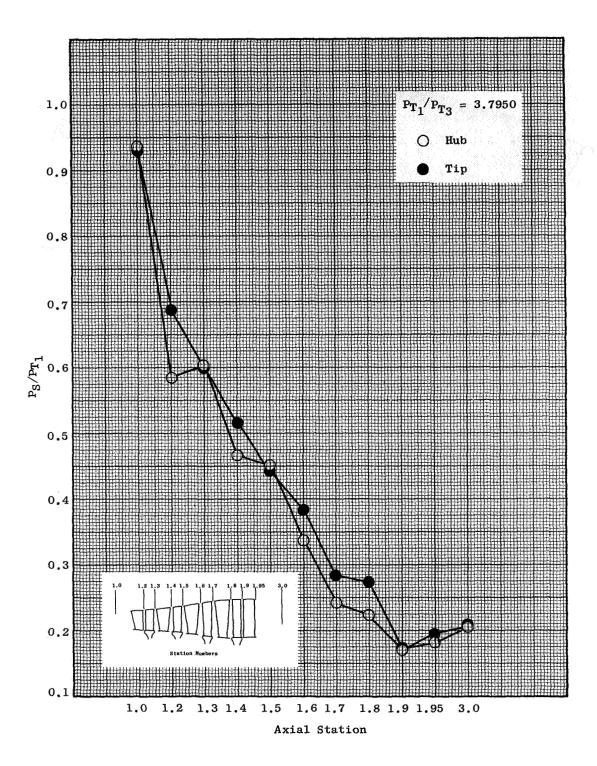


Figure 30. Normalized Static Pressure Vs. Axial Station, at Design Speed (Concluded).

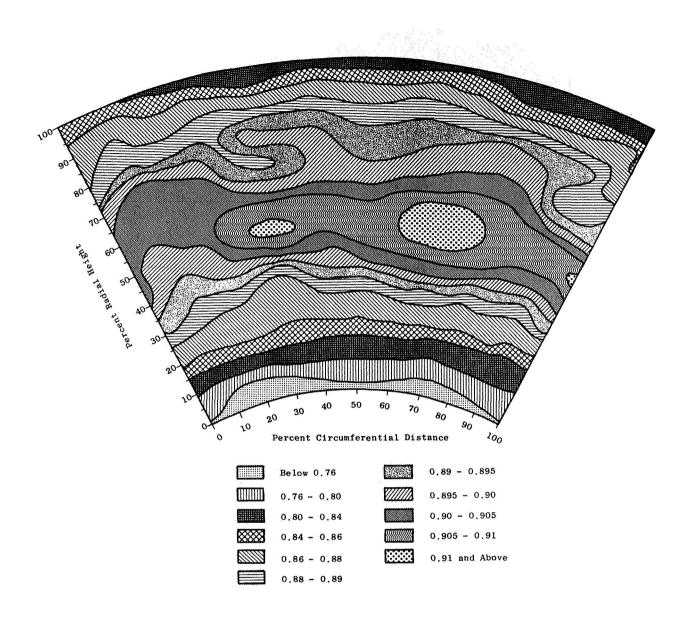


Figure 31. Turbine Efficiency Contour Plot, 4-1/2-Stage.

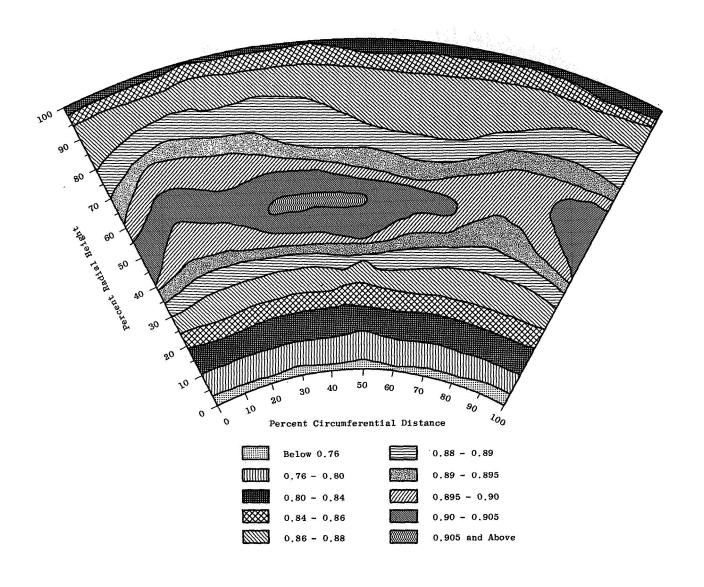


Figure 32. Turbine Efficiency Contour Plot, 4-Stage.

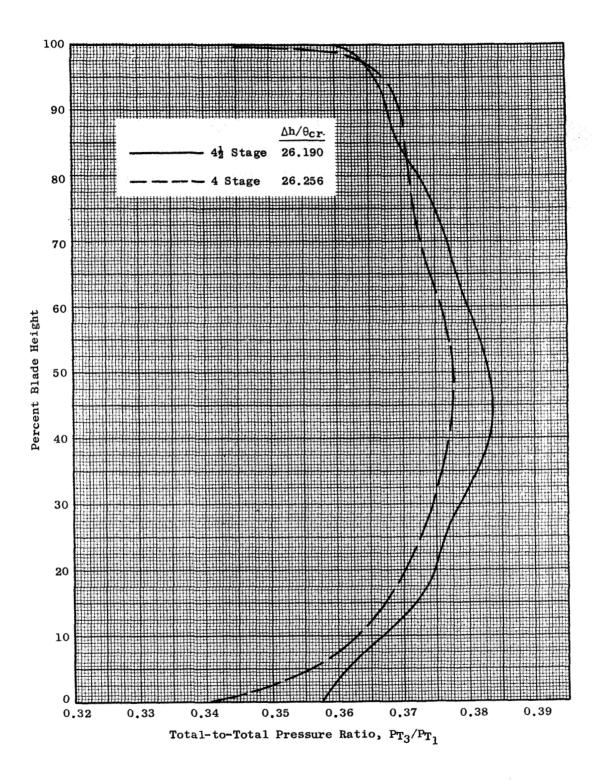


Figure 33. Normalized Exit Radial Total Pressure Profile.

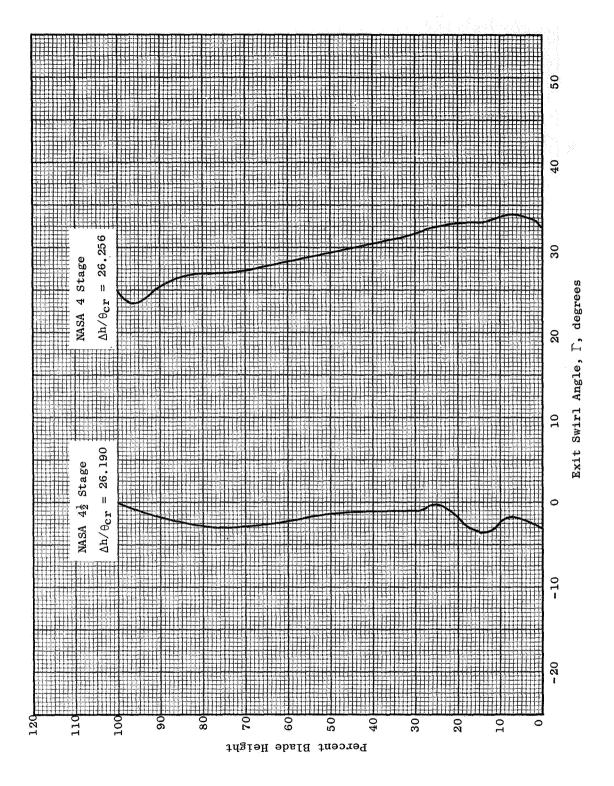


Figure 34. Radial Exit Swirl Profile.

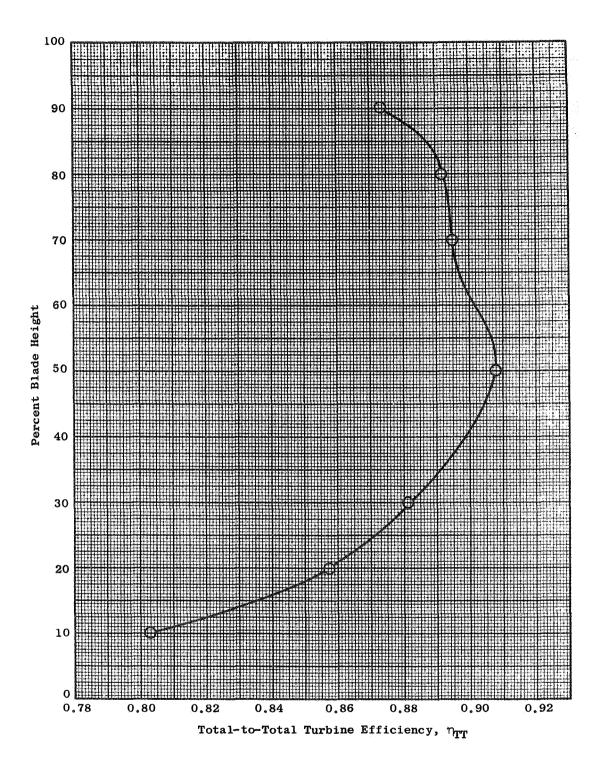


Figure 35. Radial Total-to-Total Efficiency Profile for 4-1/2-Stage Configuration.

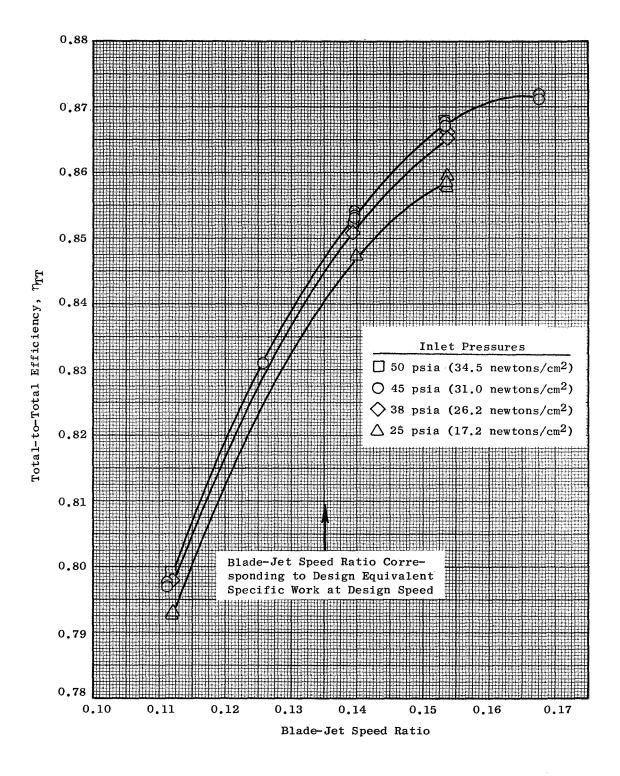


Figure 36. Total-to-Total Efficiency Vs. Blade - Jet Speed Ratio for Various Inlet Pressures.

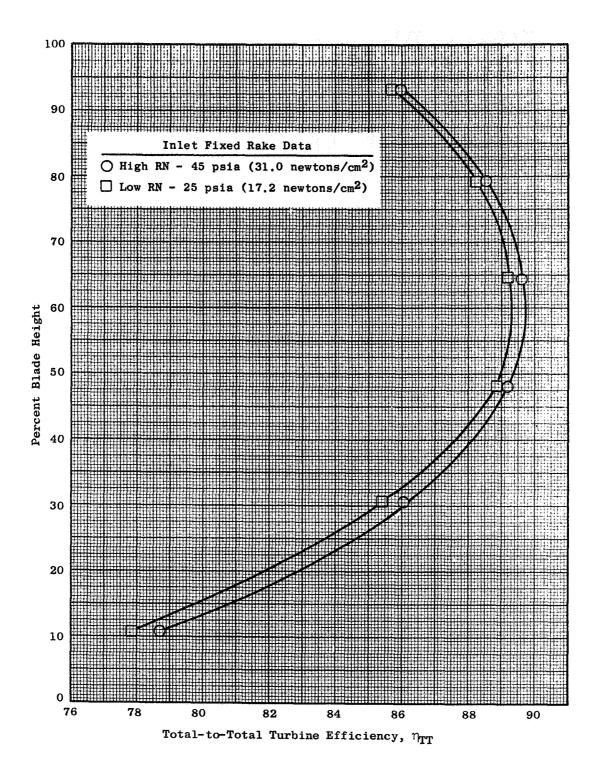


Figure 37. Radial Efficiency Profiles Based on Fixed Rake Data for High and Low Reynolds Numbers

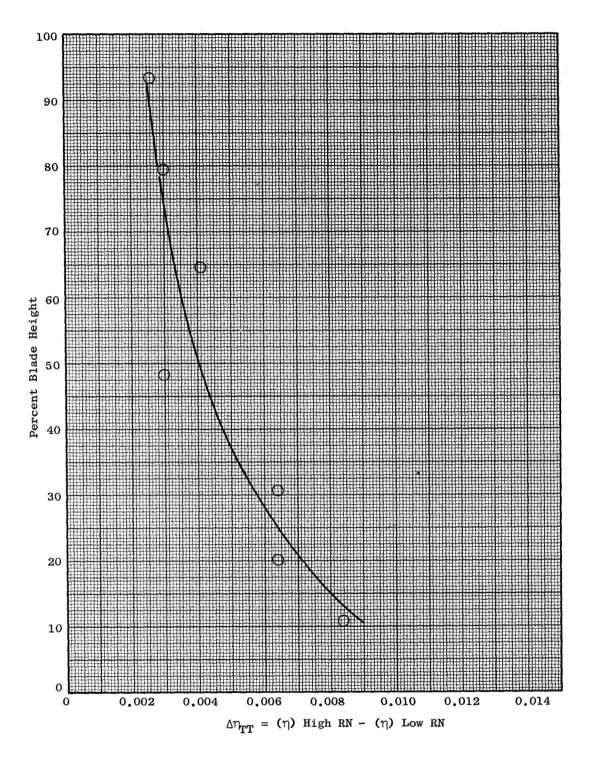
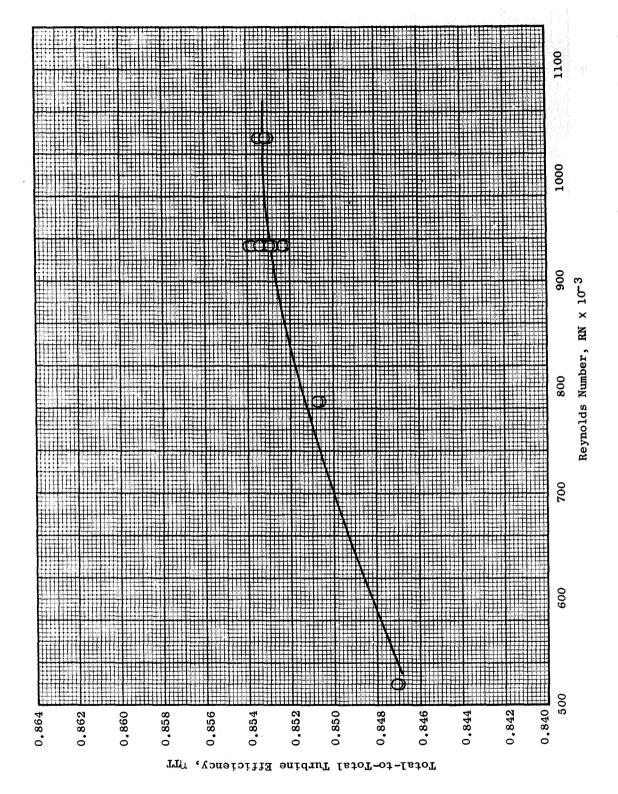


Figure 38. Percent Blade Height Vs. Change in Efficiency for High and Low Reynolds Numbers.



Total-to-Total Turbine Efficiency Vs. Reynolds Number at Design Equivalent Speed. Figure 39.

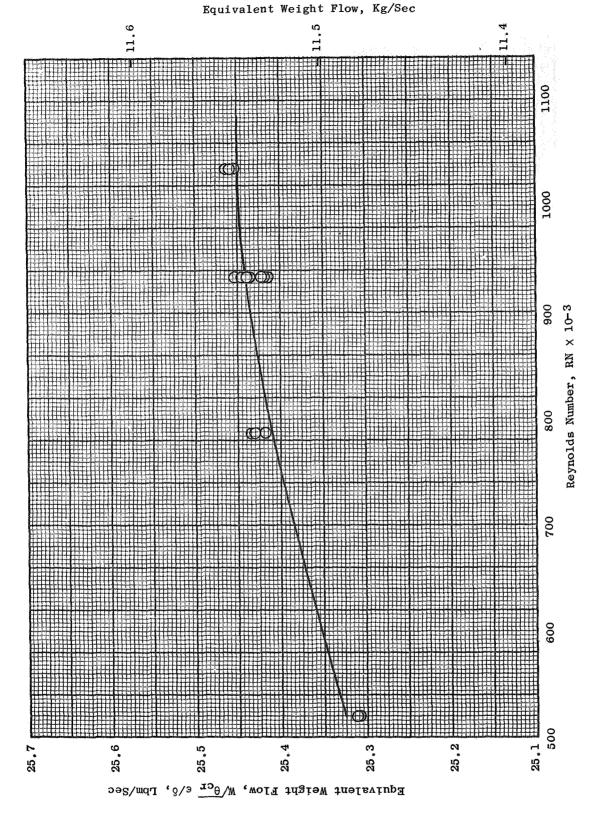


Figure 40. Equivalent Weight Flow Vs. Reynolds Number at Design Equivalent Speed.

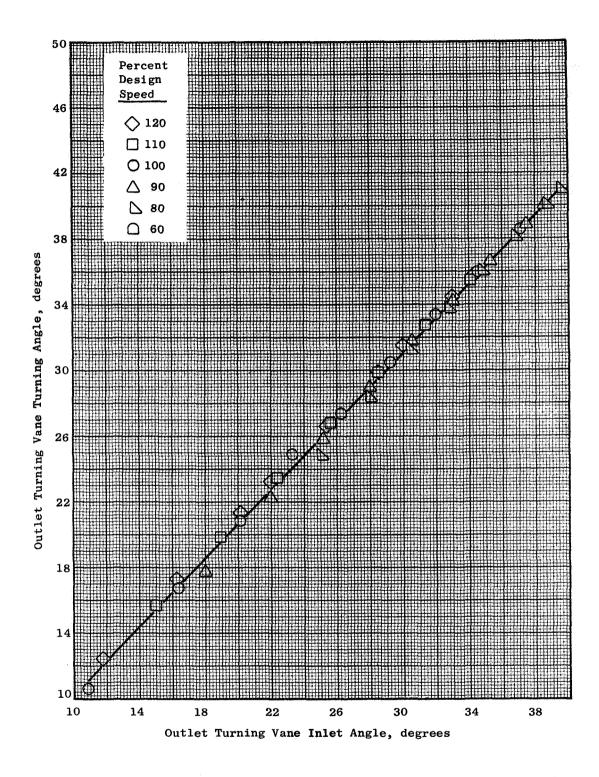
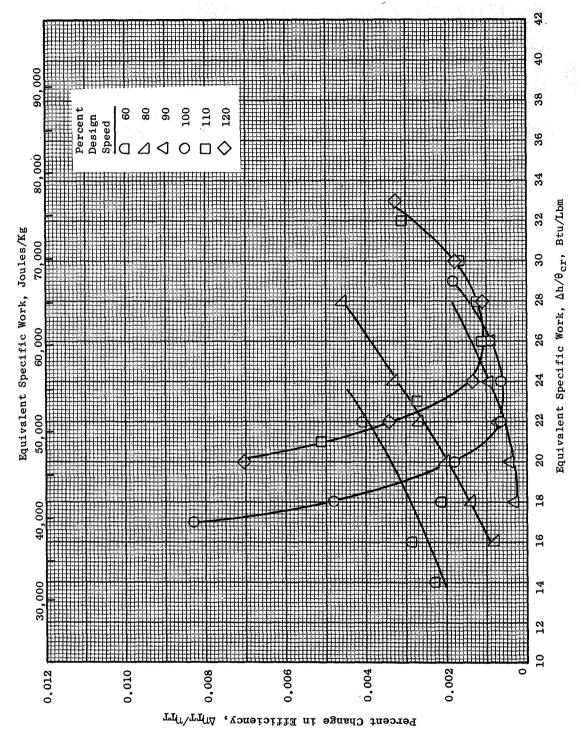
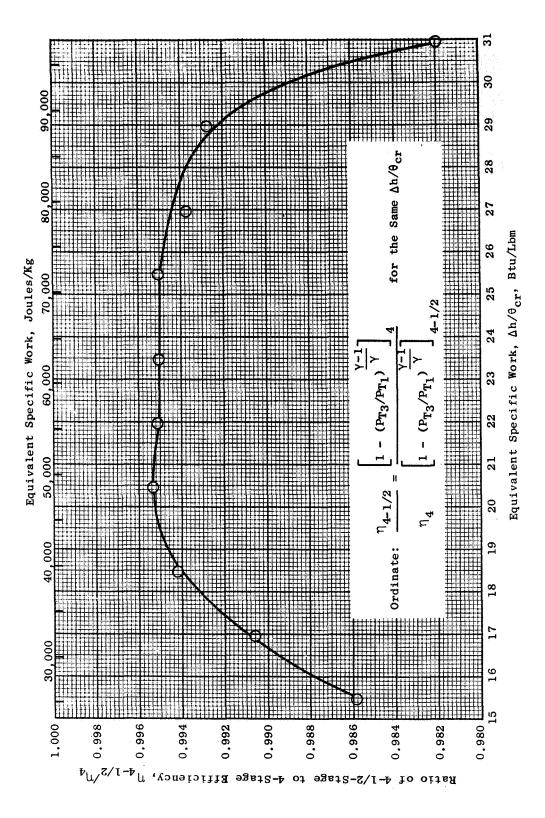


Figure 41. Outlet Turning Vane Turning Angle Vs. Outlet Turning Vane Inlet Angle at the Pitchline.



Performance Comparison of 4- and 4-1/2-Stage Turbines, Based on Calculated Exit Total Pressure. Figure 42.



Performance Comparison of 4- and 4-1/2-Stage Turbines, Based on Measured Exit Total Pressure for 100% Design Speed. Figure 43.

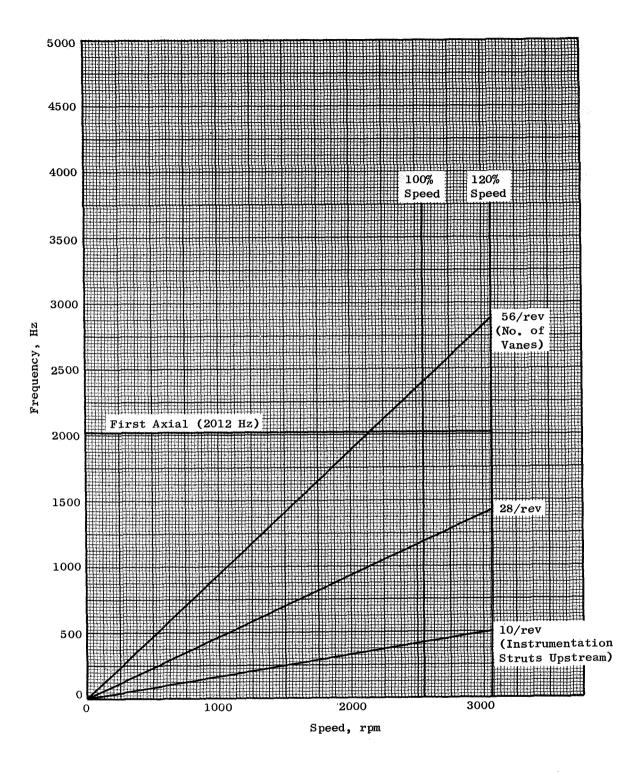


Figure 44. Most Probable Modes of Vibration, Stage One Blade.

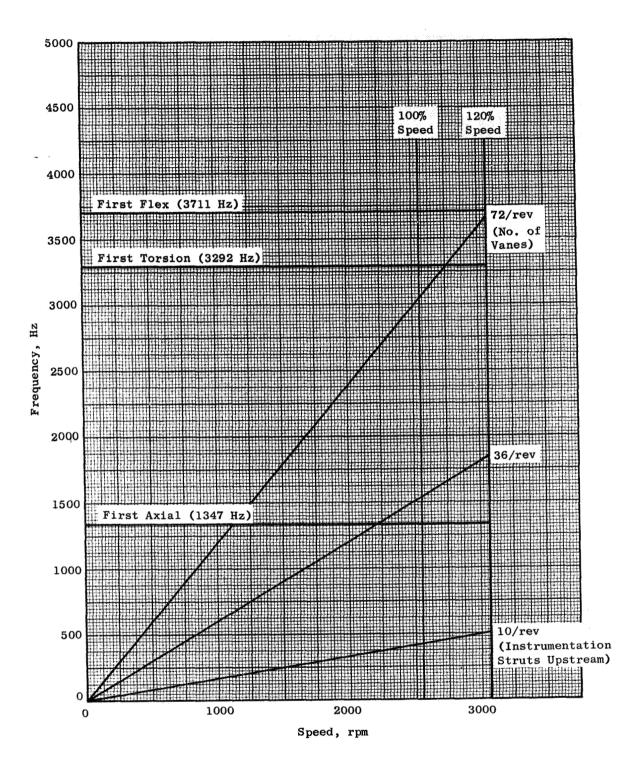


Figure 45. Most Probable Modes of Vibration, Stage Two Blade.

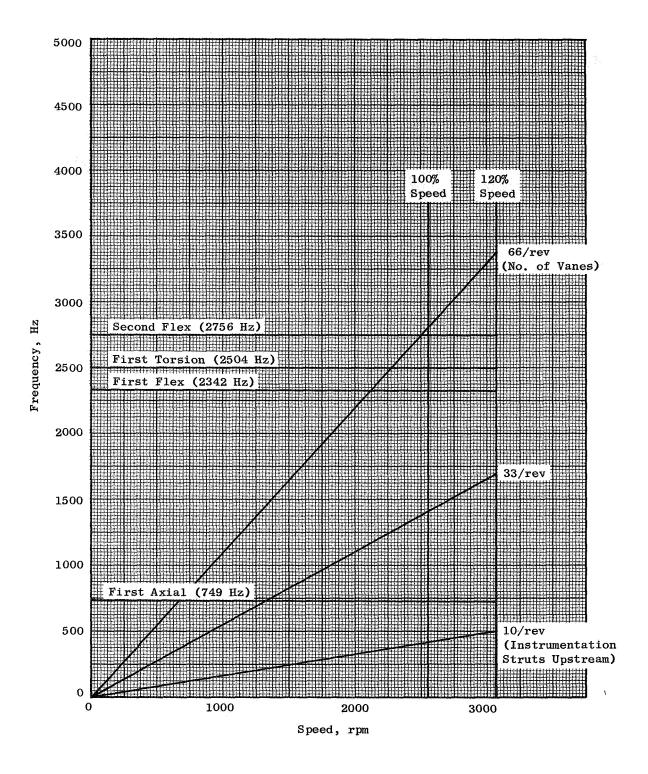


Figure 46. Most Probable Modes of Vibration, Stage Three Blade.

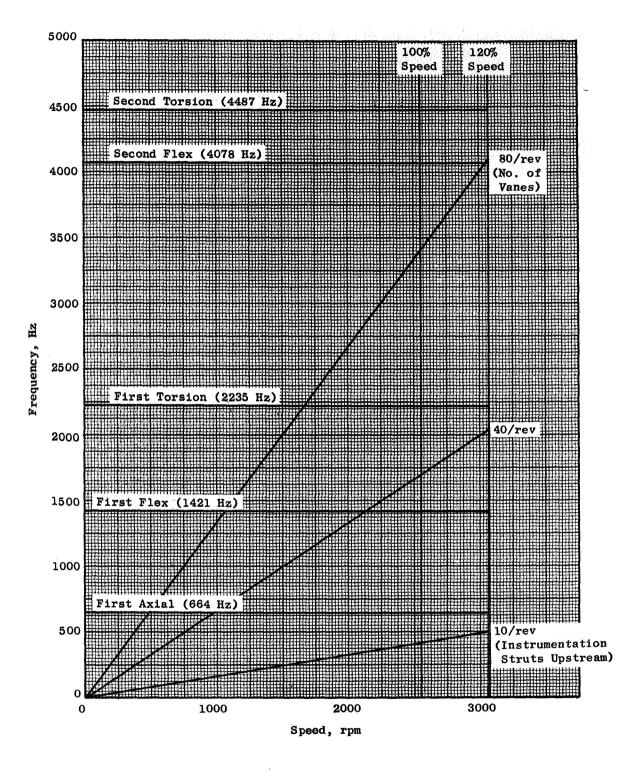
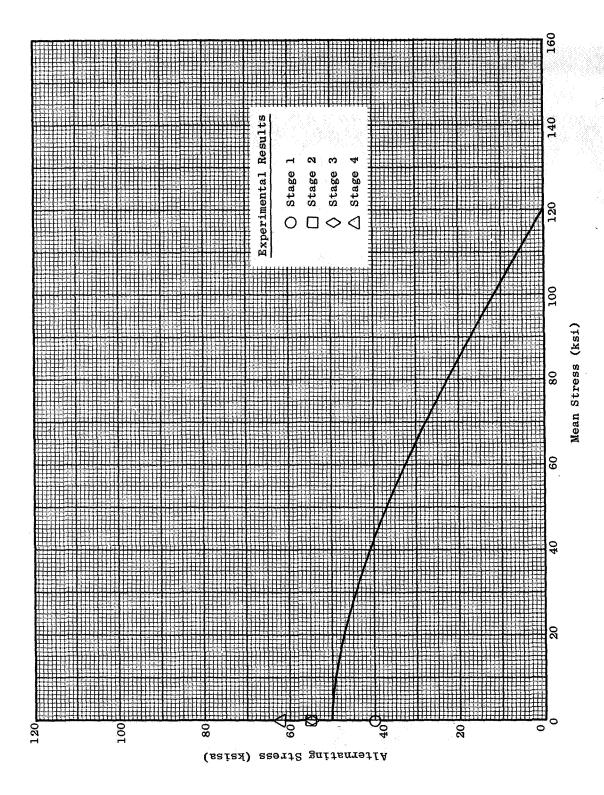
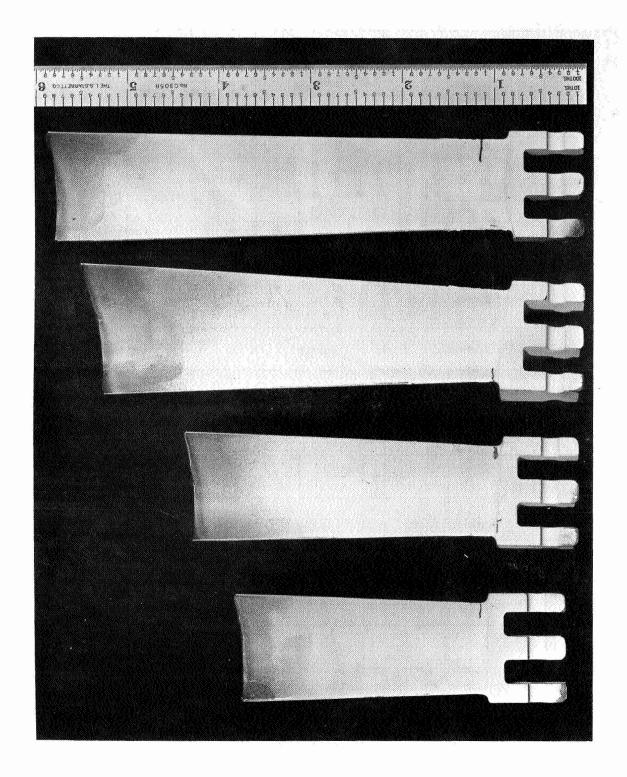


Figure 47. Most Probable Modes of Vibration, Stage Four Blade.



igure 48. Goodman Diagrams for 410 Stainless Steel.



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